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PULSE MODE PERFORMANCE MODEL COMPUTER PROGRAM DOCUMENTATION AND USER'S GUIDE. VOLUME I

W. D. Chadwick

Rockwell International Corporation

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PULSE MODE PERFORMANCE MODEL COMPUTER PROGRAM DOCUMENTATION AND USER'S GUIDE

VOLUME I

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Pulse Mode Performance Model computer program has been developed to provide an analytical tool for accurately predicting the pulse-mode performance of attitude control rocket engines. Specifically, the principal performance parameters predicted are propellant flows, total impulse and mean specific impulse for individual pulses and for overall mission duty cycles. The pulse mode operation is applicable for pulse widths which are long enough for thrust to approach its steady-state level and for pulse rates which are

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This volume of the Users Guide, along with three others, and the final report (AFRPL-TR-72-16), contains sufficient descriptive information and instructions for knowledgeable people to use the Pulse Mode Performance Model computer program with a minimum of difficulty. The first volume describes the computer program, its required input data, special operating instructions and output. Volume II contains a listing of the source program coding (excluding subprogram TDK), of card changes for special desk set ups and of the input data used in the example case. Volume III contains the complete printout of the example case. The last volume (IV) is a listing of the TDK source program coding.

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VOLUME I

Prepared By:

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Prepared for:

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Air Force Systems Command
United States Air Force
Edwards, California

Contract F04611-70-C-0074
November 1972

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FOREWORD

This computer program documentation was prepared by the Advanced Programs division of Rocketdyne, a division of North American Rockwell Corporation, 6633 Canoga Avenue, Canoga Park, California. This document was prepared in accordance with and in partial fulfillment of Contract F04611-70-C-0074, Pulse Mode Performance Model (Project No. 3058, Program Element No. 6.23.02F), during the period 1 July 1970 to 21 September 1972. This contract was administrered by the Air Force Rocket Propulsion Laboratory, Edwards, California. The Air Force Project Officer was Capt. S. Rosen, who replaced Dr. Clark Hawk. Initially Mr. T. A. Coultas was the Rocketdyne Program Manager, with Mr. L. P. Combs replacing him just prior to the program extension.

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INTRODUCTION

The Pulse Mode Performance Model computer program has been developed to provide an analytical tool for accurately predicting the pulse-mode performance of attitude control rocket engines. Specifically, the principal performance parameters predicted are propellant flows, total impulse and mean specific impulse for individual pulses and for overall mission duty cycles. The pulse mode operation is applicable for pulse widths which are long enough for thrust to approach its steady-state level and for pulse rates which are not so rapid as to prevent thrust from decaying below 10 percent of its steady-state level between pulses.

This document, along with the Final Report (AFRPL-TR-72-16), contains sufficient descriptive information and instructions for knowledgeable people to use the Pulse Mode Performance Model computer program with a minimum of difficulty. This first volume describes the computer program, its required input data, special operating instructions and output. Volume II contains a listing of the source program coding (excluding subprogram TDK), of card changes for special deck setups and of the input data used in the example case. Volume III contains the complete print out of the example case. The last volume (IV) is a listing of the TDK source program coding.

COMPUTER PROGRAM DESCRIPTION

The PMPM computer program consists of many subprograms and subroutines The complete FORTRAN coding of the PMPM computer program is presented in Volume II and IV of this program documentation. All of the subprograms and subroutines are included in this card listing, except for standard mathematical and service routines which are generally available in the FORTRAN library. In this section, the primary purpose of each of the subprograms and some of the major subroutines are described briefly. To aid in viewing the overall structure, execution order and logic, flow charts of the subprograms (except for TDK) and some of the major subroutines are presented in Figures 1 through 9. The complete description of the computer model is presented in the PMPM final report (AFRPL-TR-72-16).

MAIN

The MAIN program of PMPM is an executive control program which directs the order of executing its subroutines and subprograms. Input control data is checked to determine which subprograms are to be included in the analysis. Subroutine PPIN performs the function of reading properties of the propellants which are required in one or more subprograms. Subroutine ENGBAL solves the engine system flowrates and pressures based on estimated performance efficiencies. The primary subprograms are PMDER, PULSE and DCYCLE.

PMDER

The PMDER subprogram block performs the steady-state combustion performance analysis. Its purpose is to calculate steady-state performance parameters such as: propellant flowrates, chamber pressure, characteristic velocity (c*), thrust coefficient, thrust, specific impulse and mean fuel and oxidizer combustion rate functions. Subroutine PMDER is the executive control program of this subprogram block. Subprograms to this block include LISP, PMSTC, TRANS and TDK.

LISP

Subprogram LISP performs the propellant injection, atomization and spray distribution analysis based on specific injector design parameters and the pressure drop across the injector orifices. Empirical spray atomization and distribution functions are built into the program for common types of impinging jet injector element types. Spray is formed at the impingement points, and it spreads out from each of these points in rays. The LISP analysis covers a region from the injector face to a distance downstream specified by input data. At the downstream location the mass flux at each point in a mesh plane is calculated by summing the flux contribution from each injector element. LISP defines the mass and mixture ratio spray distribution, estimates the amount of spray vaporization and predicts the mean spray drop sizes in a plane downstream from the injector face.

PMSTC

PMSTC is the streamtube combustion subprogram block. Its primary purpose is to model the spray vaporization between the LISP region and the throat plane. A single stream tube analysis precedes the multiple stream tube analysis to obtain an approximate vaporization efficiency. Spray and gas data from LISP are arranged into axisymmetric stream tubes. Fuel and oxidizer sprays are further subdivided into discrete drop sizes to give a distribution about their mean size. The interaction of the spray vaporization and gas dynamics is calculated in a step-wise procedure downstream just through the throat. Stream tube flow is coupled by the overall chamber area constraint, assuming constant pressure in axial planes until the transonic flow region is reached. In the later region, a pressure profile is established from a transonic flow solution from subprogram TRANS. PMSTC predicts combustion performance parameters and efficiency, and it provides gas data along a slightly supersonic isobar for the TDK nozzle performance subprogram.

TRANS

The TRANS subprogram generates a family of isobaric lines throughout the transonic flow regime. The isobars are used to determine pressure profiles in the multiple stream tube analysis of PMSTC. A homogeneous flow is assumed based on mean gas properties obtained from the single stream tube analysis of PMSTC.

TDK

The TDK subprogram is a massive two-dimensional (axisymmetric) program which calculates the supersonic, kinetic expansion of the combustion gas in the nozzle. Its purpose in PMPM is to provide the thrust coefficient efficiency.

PULSE

Subprogram PULSE characterizes pulse performance by modeling the transient performance of several sequences of "standard" width pulses in which the off-time is varied between pulses and by setting up tables of parametric performance data. Its transient combustion analysis is done in subroutine TCØMB.

TCØMB

The TCØMB subroutine analytically simulates the transient performance of a propellant feed system, propellant ignition process, spray vaporization and gas accumulation in and flow through the combustion chamber. Spray vaporization is performed in subroutine GASGEN.

GASGEN

In subroutine GASGEN, fuel and oxidizer spray ensembles are formed as propellant is injected into the chamber. Each spray ensemble is vaporized at the rate specified by the spray vaporization rate functions calculated in PMSTC. The purpose of this subroutine is to determine the transient flowrates of fuel and oxidizer gases being supplied to the chamber.

DCYCLE

The DCYCLE subprogram analyzes the pulse-by-pulse and cumulative performance of any sequence of pulses, or mission duty cycle. Performance of individual pulses is synthesized by subroutine SYNTHE.

SYNTHE

Subroutine SYNTHE synthesizes pulse performance by using the parametric performance tables of "standard" width pulses generated in PULSE to determine the start and decay performance of each pulse and by accounting for pulse width by adjusting the center of the pulse using steady-state performance for a duration equal to the difference between its width and the "standard" pulse width. Chamber wall temperature is calculated as a function of "on-time" and "off-time", and the pulse performance is adjusted as a function of wall temperature.

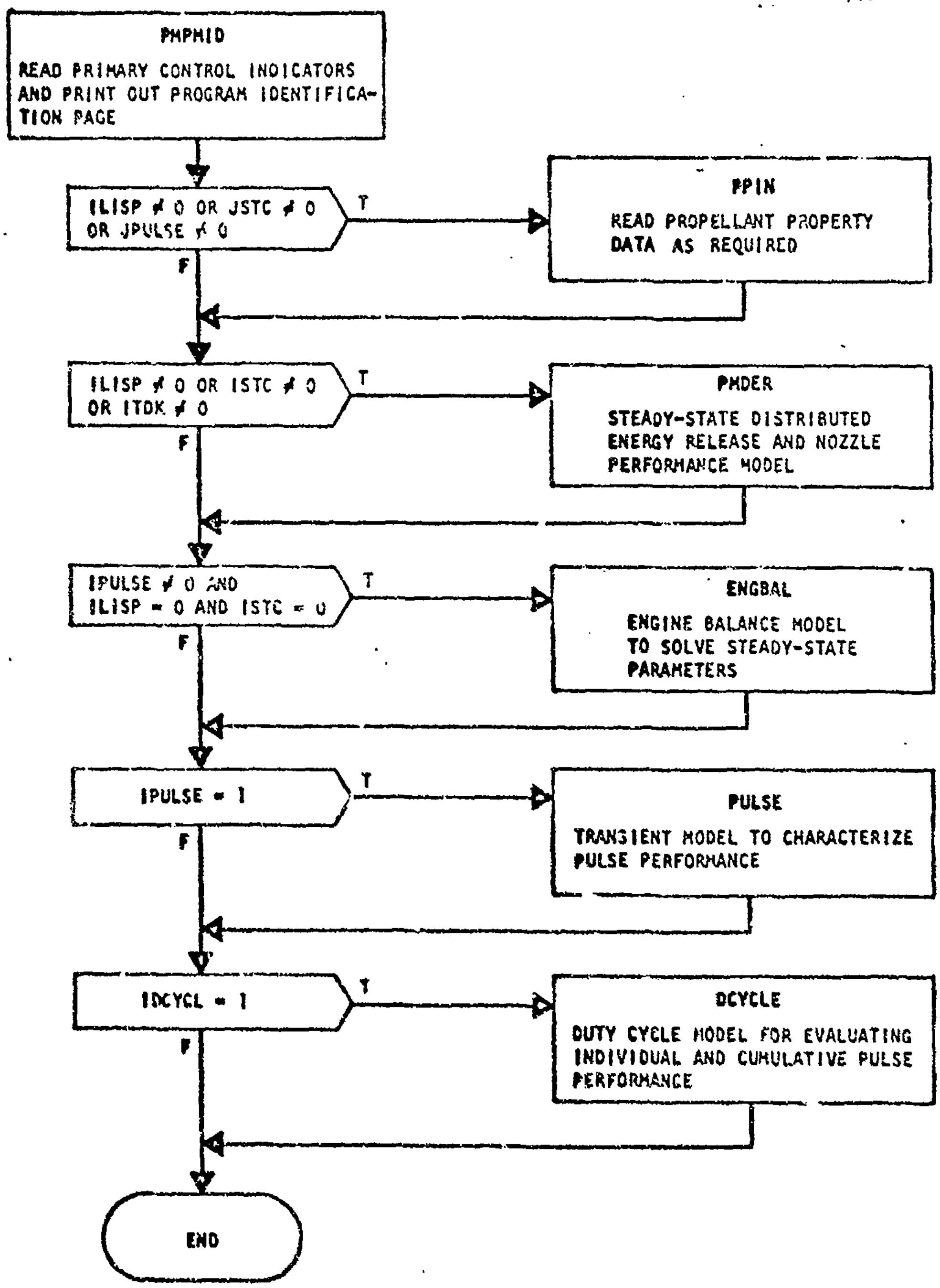


Figure 1. Flow Chart of PMPM Control Program

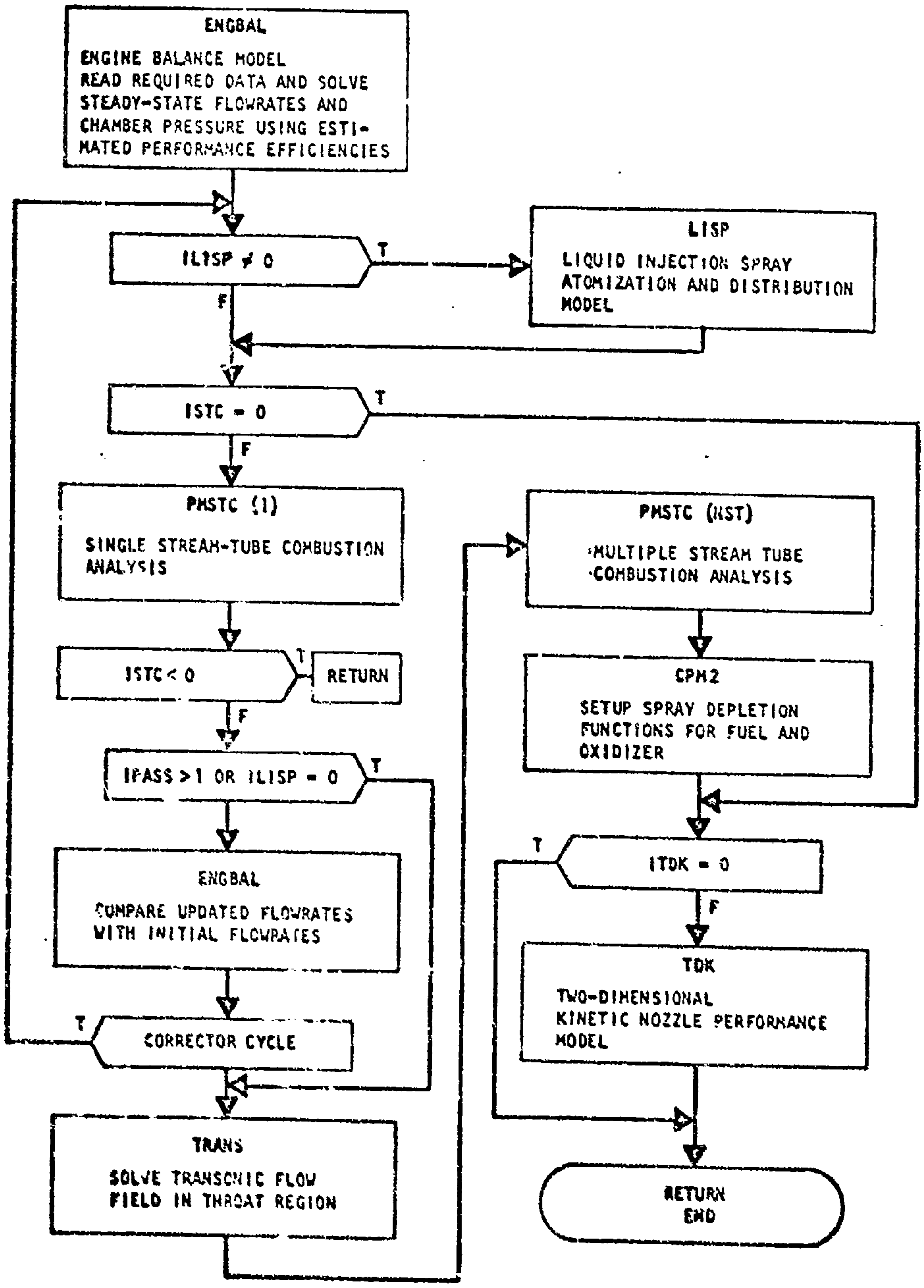


Figure 2. Simplified Flow Chart of PMDER Subprogram

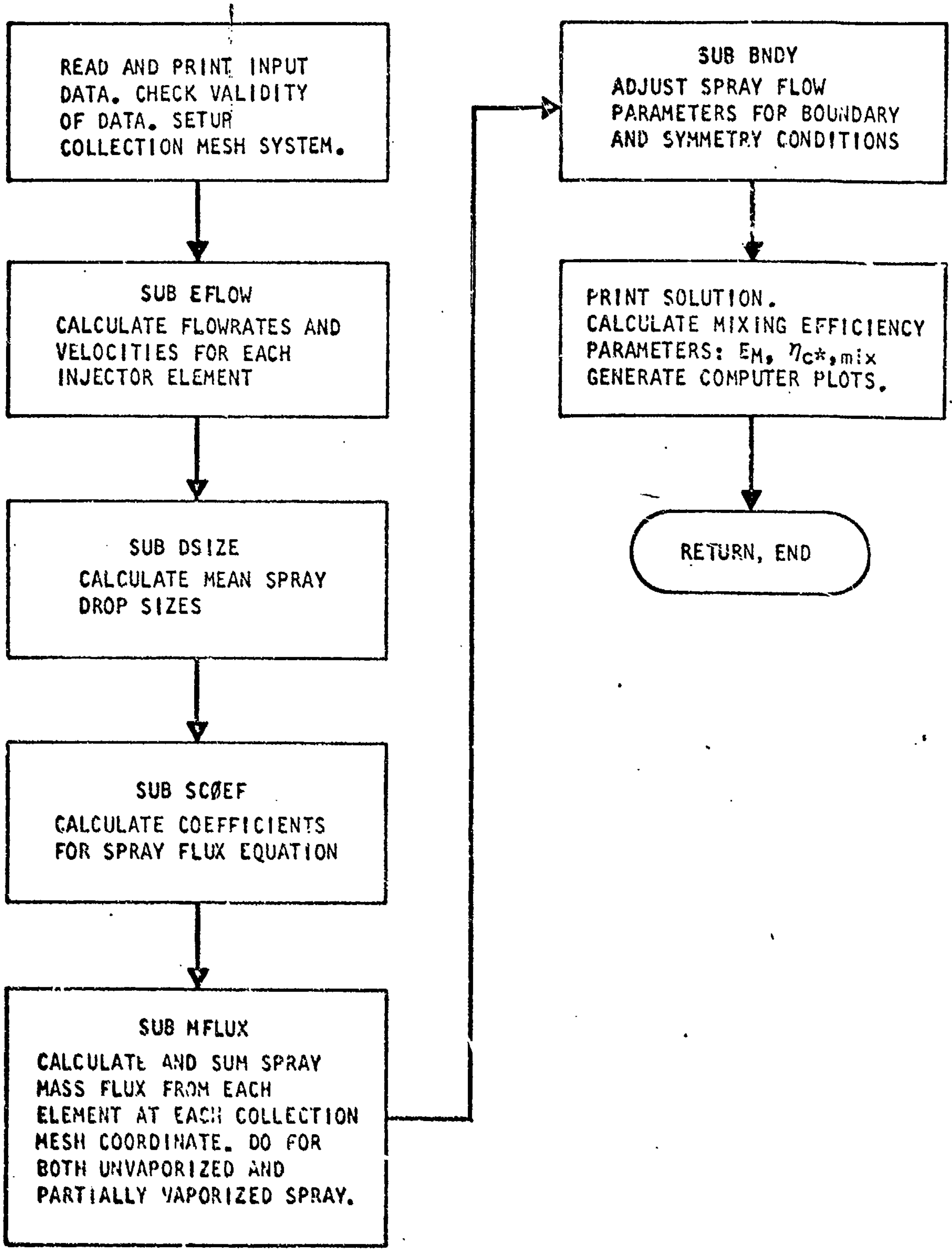


Figure 3. Flow Chart of LISP Subprogram

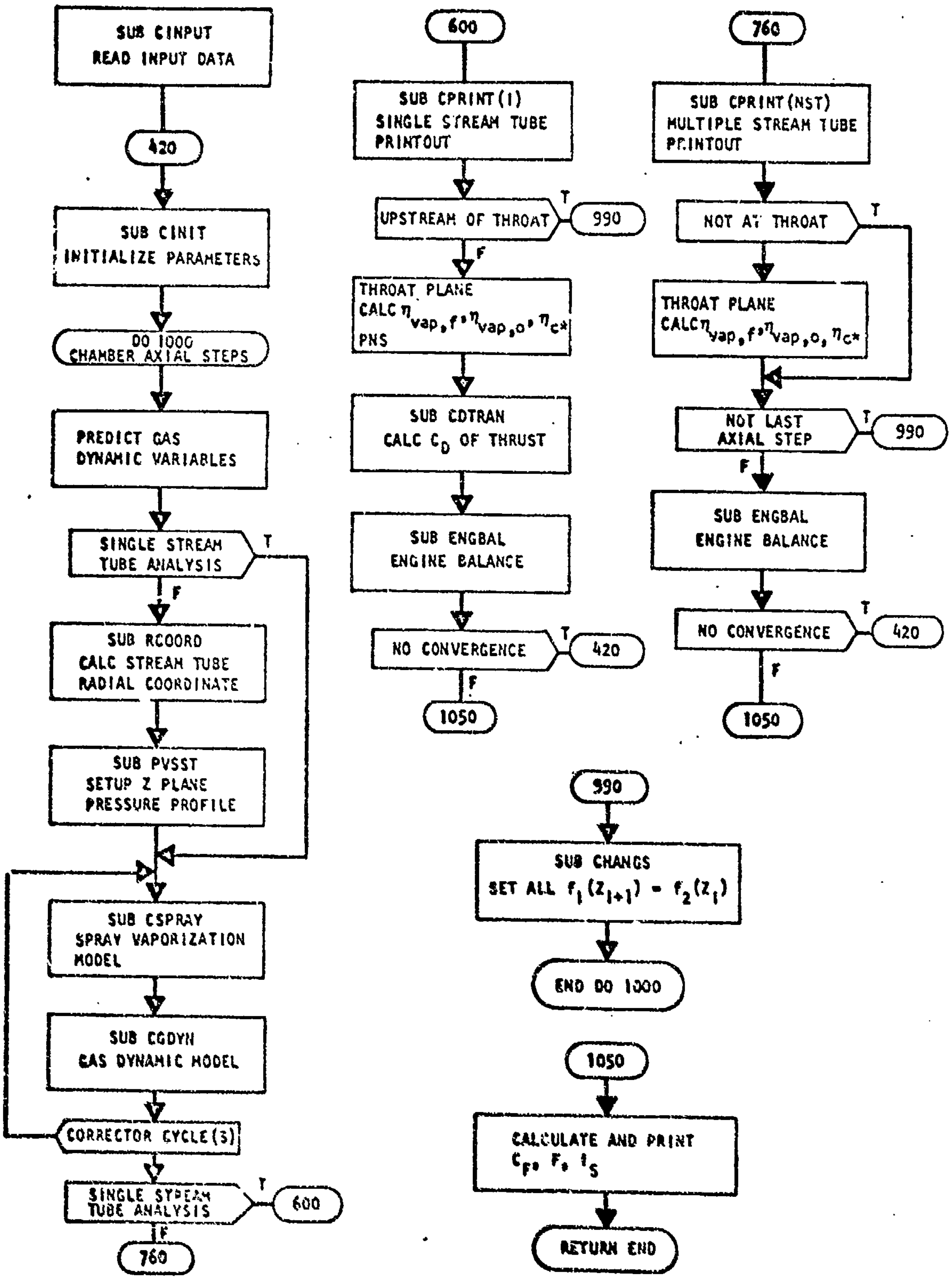


Figure 4. Simplified Flow Chart of PMSTC Subprogram

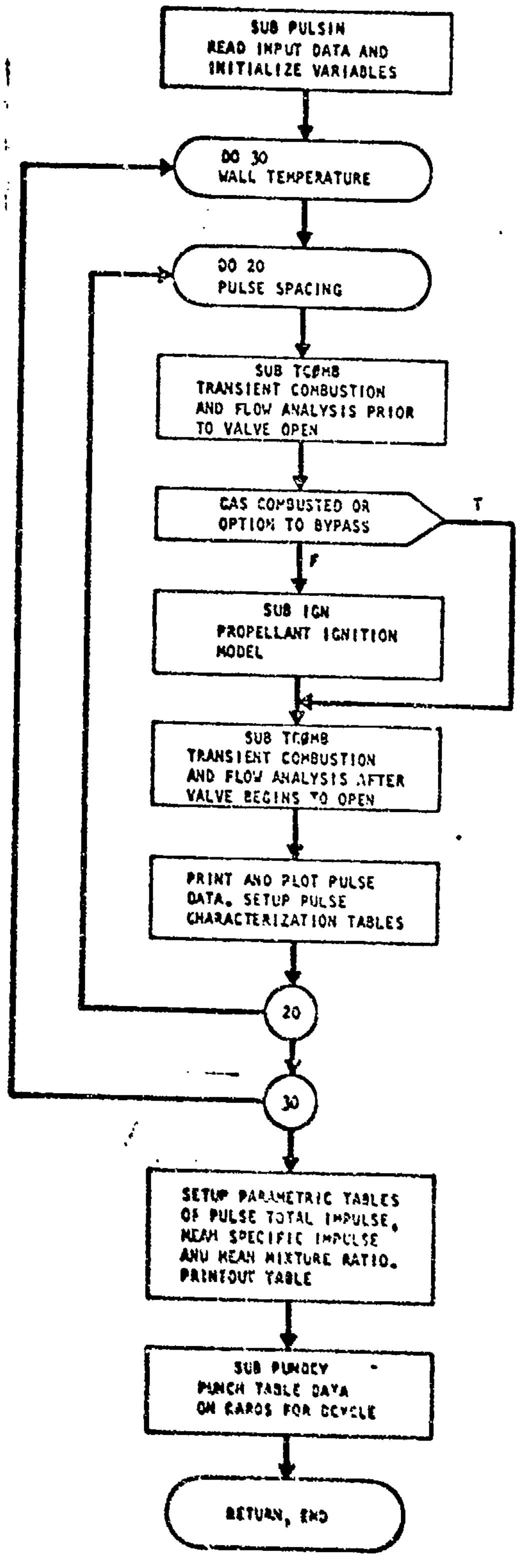


Figure 5. Simplified Flow Chart of PULSE Subprogram

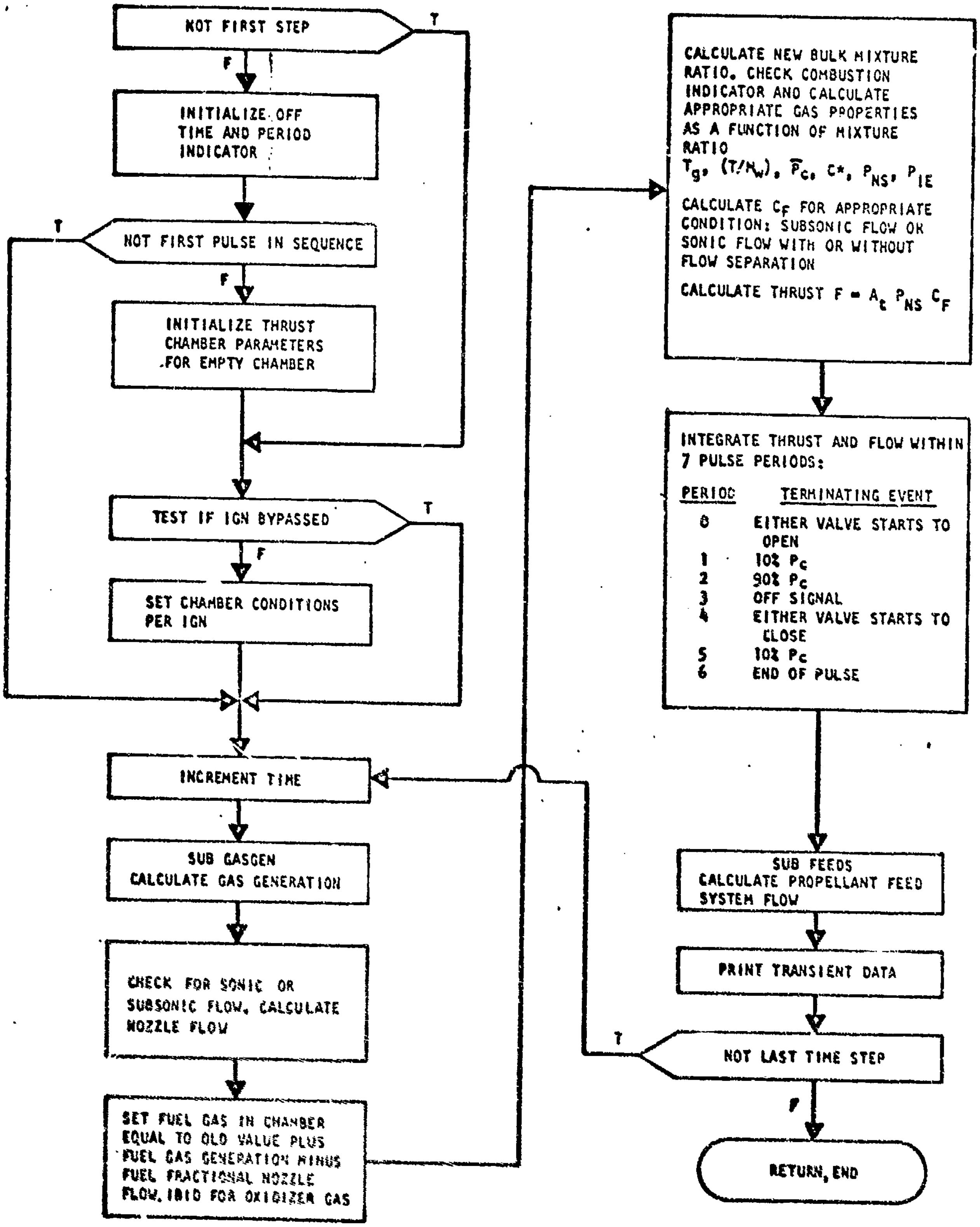


Figure 6. Simplified Flow Chart of TCØMB Subroutine

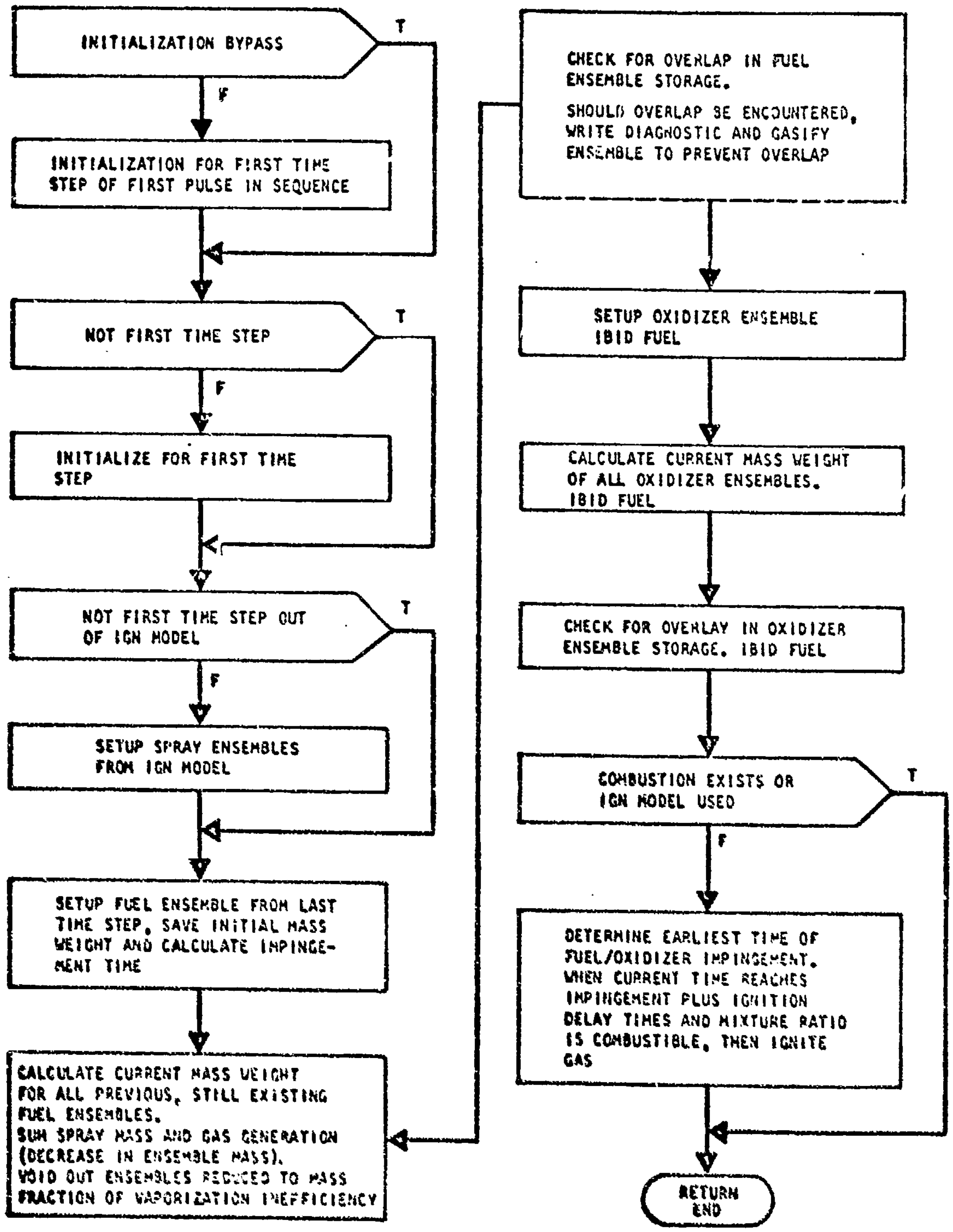


Figure 7. Simplified Flow Chart of GASGEN Subroutine

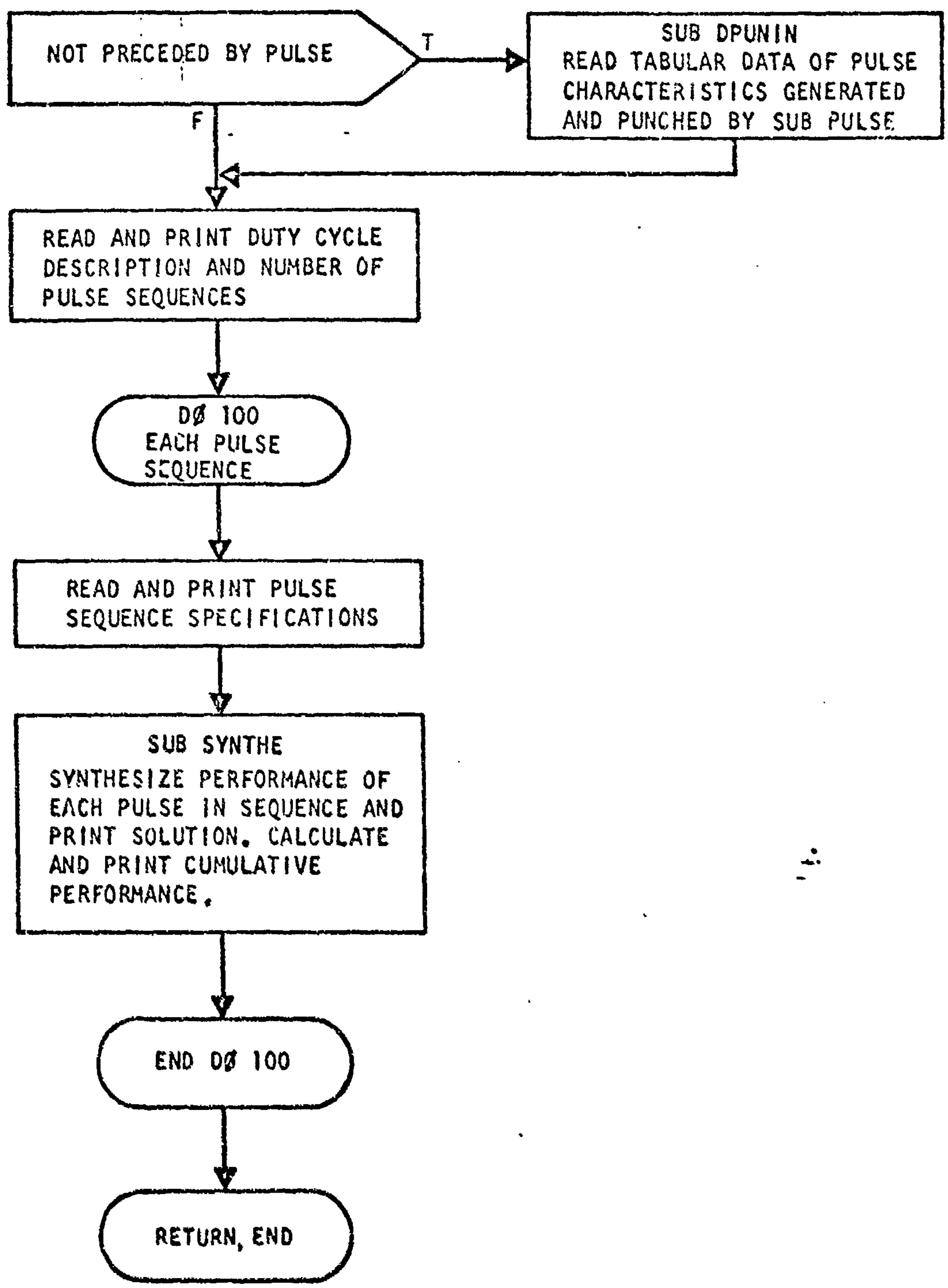


Figure 8. Flow Chart of DCYCLE Subprogram

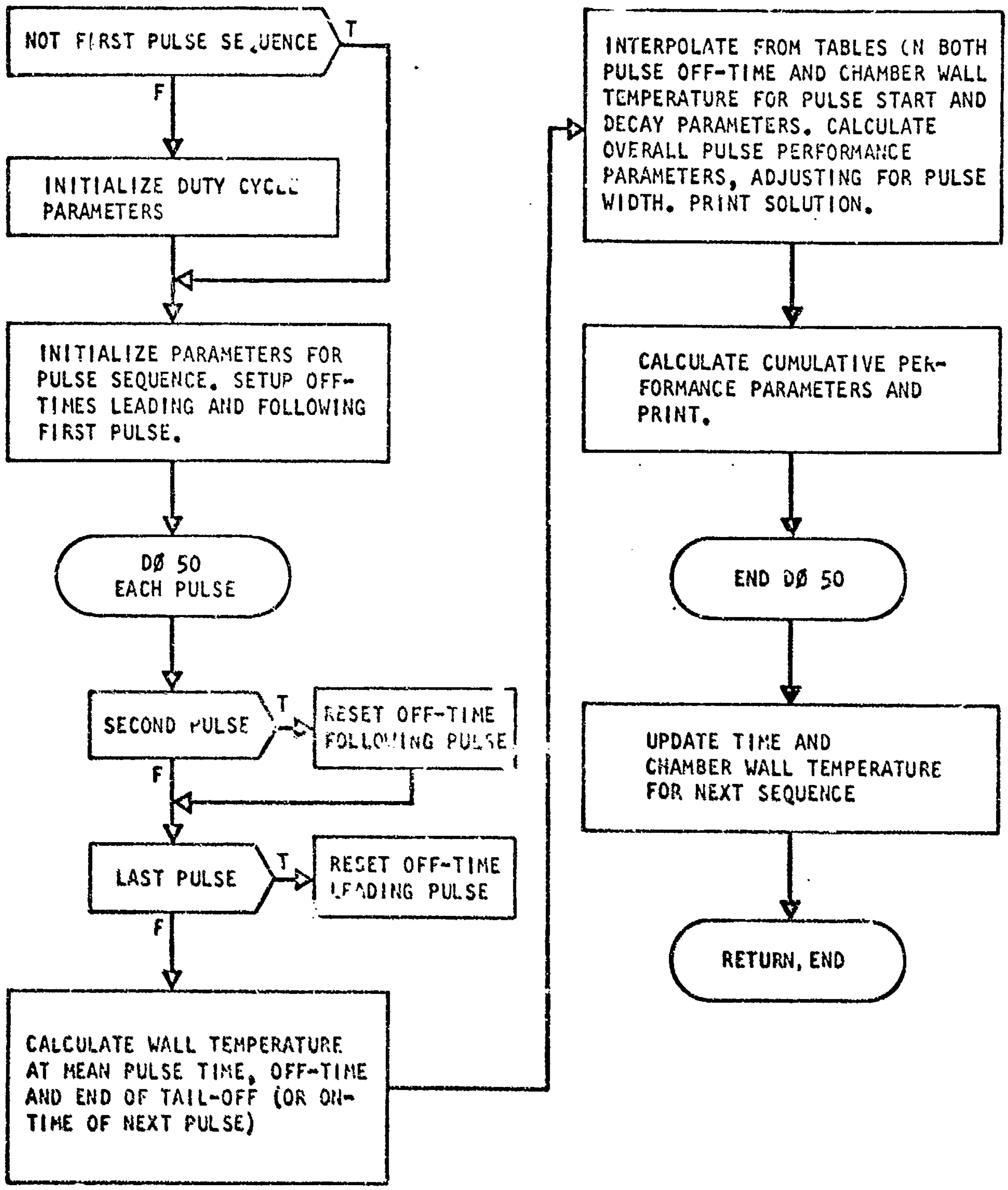


Figure 9. Flow Chart of SYNTHE Subroutine

DESCRIPTION OF INPUT DATA

In this section, the specific input data required to execute the computer program is described. The input data specifications are first listed, and then some of the more complex input data is discussed in detail.

SPECIFICATION OF INPUT DATA

The input data entries required to execute the computer program are specified in Table 1. In this table, the entries are listed by card and then further grouped by the component model which reads the data. Card identification numbers are tabulated in the first column. Although the use of these numbers is not mandatory, card numbering permits mechanical sorting of the data deck, and consistency in numbering aids in locating specific data cards. The format for entering the data is also included in the first column, enclosed in parenthesis. Standard FØRTRAN notation is used for the format specification.

The second column of Table 1 contains the FORTRAN code names of data entries. When a parenthesis enclosing an I and/or J follows the coded name, then this indicates an array, rather than a single value, is required. A description of each entry appears along side of each input code name. The description includes, when applicable, such information as: values of indicators for program options, number of cards required, number of values required, size limits and dimensional units.

Input data work sheets are printed in Table 2 to assist the user in coding data for key punching and for providing a form suitable for documenting specific input data used on each computer execution case. The intention is for the user to use these worksheets as masters and to reproduce them as they are needed.

The work sheets are laid out for an entry field width of 12 characters which is the length generally specified in the formats. The last 8 character spaces on each card are reserved for the sequence number, and the program does not read these spaces. The FORTRAN code name appears to the right of each entry field. Notes are provided to instruct the user in situations in which the inputs are to be entered only under certain conditions. When the note is placed at the top of the work sheet, it applies to all cards on that sheet. Otherwise, the notes apply to the specific card where they appear.

TABLE 1. SPECIFICATION OF INPUT DATA

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION *
		Identification and Primary Control Data (HEADER)
10,20,30,40 (18A4)	AMAT	PMPM case description. Four cards required.
50 (6I12)	ILISP ISTC ITDK IPULSE IDCYCL	Primary control options for selecting major subprograms LISP, STC, TDK, PULSE and DCYCLE, respectively, for execution. "1" to execute, "0" to bypass. Special: ISTC =-1 for single stream tube (SST) analysis without MST (multiple) analysis.
60 (6I12)	JLISP JSTC JPULSE JBØIL JIGN	Control indicators for specifying the inclusion of propellant property data required by subprograms LISP, STC, PULSE, BOIL and IGN respectively. "1" to include, "0" to omit. Special: JLISP = 2 required when injector types 1, 2 or 3 specified in LISP.
		Propellant Property Data (PPIN) (Cards 90-980)
90 (18A4)	TITLEP	Propellant description. One card.
100 (6I12)	NMR NMACH NEPS NTK	Propellant property table array sizes for mixture ratio, mach number, nozzle expansion area ratio and droplet film temperature. Maximum sizes: 18, 3, 6 and 20, respectively.
		Cards 111-573 contain theoretical equilibrium propellant combustion performance data. Mixture ratio (weight oxidizer to fuel) is the primary independent parameter with mach number as a secondary independent parameter on chamber properties.
111,2,3** (6E12.8)	TMR(I)	Combustion gas mixture ratio array. Enter NMR values arranged in either ascending or descending order.
120 (6E12.8)	TMACH(J)	Combustion gas mach number array. Enter NMACH values in ascending order. Normally, enter 3 values with 1st = 0. Last (or only) value should be = 1.
211,2,3 ** (6E12.8)	TSTAT(I)	Combustion gas static temperature array. Enter values to correspond with the TMR mixture ratio array and mach number TMACH(1). NMR values required. Units: ^{o}R.

* See section on Discussion of Input Data for additional detail.

** Unit cards not required for specific array size.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
221,2,3* (6E12.8)	TVIS(I,1)	Combustion gas static viscosity array. Enter values to correspond with the TMR mixture ratio array and mach number TMACH(1). NMR values required. Units: lb_m/ft-hr.
231,2,3* (6E12.8)	TGAM(I,1)	Same as above for frozen gamma array. Unit dimensionless.
241,2,3* (6E12.8)	TMW(I,1)	Same as above for molecular weight array. Units: lb_m/mole
251,2,3* (6E12.8)	TSVON(I)	Same as above for sonic velocity array. Units: ft/sec.
311-353 (6E12.8)		Combustion gas property arrays corresponding with cards 211-253, except for values corresponding with mach number TMACH(2). Omit card sequence, if NMACH less than 2.
411-453 (6E12.8)		Same as above except for values corresponding with mach number TMACH(3). Omit card sequence if NMACH less than 3.
501,2,3* (6E12.8)	CSTR(I)	Combustion gas, theoretical c* array arranged to correspond with TMR mixture ratio array.
508 (6E12.8)	TEPS(J)	Nozzle expansion area ratio array. NEPS values arranged in ascending order.
511,2,3* (6E12.8)	TCF(I,1)	Theoretical thrust coefficient, C_F, array corresponding with TMR mixture ratio array and expanded to TEPS(1) area ratio.
521,2,3	TCF(I,2)	Same as above except for expansion to TEPS(2). Omit cards if NEPS < 2.
531,2,3	TCF(I,3)	Same as above except for expansion to TEPS(3). Omit cards if NEPS < 3.
541,2,3	TCF(I,4)	Same as above except for expansion to TEPS(4). Omit cards if NEPS < 4.
551,2,3	TCF(I,5)	Same as above except for expansion to TEPS(5). Omit cards if NEPS < 5.
561,2,3	TCF(I,6)	Same as above except for expansion to TEPS(6). Omit cards if NEPS < 6.

* Omit cards not required for specific array size.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
		LISP Propellant Data (Cards 570-590. Include when JLISP≠0)
570 (6E12.8)	DENS1	Density of injected fuel. Units: lb_m/ft^3.
	DENS2	Density of injected oxidizer.
580 (6E12.8)	PX	Reference pressure for wet bulb density. Units: psia.
	DNSAX1	Saturation density of fuel. Units: lb_m/ft^3.
	DNSAX2	Saturation density of oxidizer.
	SDNSA1	Slope of fuel wet bulb density vs. pressure.
	SDNSA2	Slope of oxidizer wet bulb density vs. pressure.
	CKP1	Mean fuel evaporation coefficient (Modified k_f') in impingement-to-collection plane region. Units: in^2/sec.
590 (6E12.8)	CKP2	Mean oxidizer evaporation coefficient (modified k_o') in impingement-to-collection plane region. Units: in^2/sec.
	STEN1	Fuel surface tension. Units: dyne/cm.
	STEN2	Oxidizer surface tension.
	VISC1	Fuel viscosity. Units: lb_m/ft-sec.
	VISC2	Oxidizer viscosity.
		STC Propellant Data (Cards 600-730. Include when JSTC≠0)
600,610* (6E12.8)	TVF(I)	Droplet film temperature array ranging from drop temperature to maximum combustion gas temperature used in tabulating CPVAPF & TCØNVF. Enter NTK values. Units: °R
620,630* (6E12.8)	CPVAPF(I)	Fuel vapor specific heat array corresponding with TVF array. Units: BTU/lb_m-°R.
640,650* (6E12.8)	TCØNVF(I)	Thermal conductivity of fuel vapor-combustion gas film corresponding with TVF array. Units: BTU/ft-hr-°R.
660,670* (6E12.8)	TVØ(I)	Same as TVF except used in tabulating CPVAPØ & TCONVØ.
680,690* (6E12.8)	CPVAPØ(I)	Same as CPVAPF except for oxidizer.
700,710* (6E12.8)	TCØNVØ(I)	Same as TCØNVF except for oxidizer.
720 (6E12.8)	TNBF	Fuel normal boiling point temperature. Units: °R.

* Omits cards not required for specific array size.

TABLE I. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
720 Continued	TNBØ	Fuel normal boiling point temperature. Units: ^oR.
	RHØFNB	Fuel liquid density of at normal boiling point. Units: lb_m/ft^3.
	RHØØNB	Same as above except for oxidizer.
	TCRITF	Fuel critical temperature. Units: ^oR
	TCRITØ	Oxidizer critical temperature.
730 (6E12.8)	TBF	Fuel droplet saturation temperature at P_c. Units: ^oR.
	TBØ	Oxidizer droplet saturation temperature at P_c.
	RHØBF	Fuel droplet density at saturation temperature corresponding to P_c. Units: lb_m/ft^3.
	RHØBØ	Same as RHØBF except for oxidizer.
		STC, BOIL AND IGN Propellant Data(Card 740. Include when JSTC≠0 or JBØIL≠0 or JIGN≠0)
740 (6E12.8)	WTMLLF	Fuel liquid molecular weight. Units: lb_m/mole.
	WTMLLØ	Oxidizer liquid molecular weight. Units: lb_m/mole.
	WTMLVF	Fuel vapor molecular weight. Units: lb_m/mole.
	WTMLVØ	Oxidizer vapor molecular weight. Units: lb_m/mole.
	DHVF	Fuel latent heat of vaporization (plus sensitive heat to raise temperature of injected fuel to saturation temperature). Units: Btu/lb_m.
	DHVØ	Same as DHVF except for oxidizer.
		PULSE Propellant Data(Cards 750-980.Include when JPULSE≠0)
750 (6I12)	NRHØF	Size of fuel liquid density-temperature table ($\leq$ 20).
	NRHØØ	Size of oxidizer liquid density-temperature table ($\leq$ 20).
	NPVAPF	Size of fuel vapor pressure-temperature table ($\leq$20).
	NPVAPØ	Size of oxidizer vapor pressure-temperature table ($\leq$ 20).
760,770*	TTRLF(I)	Temperature array for fuel liquid density array. Enter NRHØF values. Units: ^oR.
780,790* (6E12.8)	TRHØF(I)	Fuel liquid density array corresponding with TTRLF temperature array. Units: lb_m/ft^3
800,810* (6E12.8)	TTRLØ(I)	Temperature array for oxidizer liquid density array. Enter NRHØØ values. Units: ^oR.
820,830* (6E12.8)	TRHØØ(I)	Oxidizer liquid density array corresponding with TTRLØ temperature array. Units: lb_m/ft^3.
840,850* (6E12.8)	TTPVF(I)	Temperature array for fuel vapor pressure array. Enter NPVAPF values. Units: ^oR.

*Omit or add cards as required for specific array size.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
860,870* (6E12.8)	TPVAPF(I)	Fuel vapor pressure array corresponding with TTPVF temperature array. Units: psia
880,890* (6E12.8)	TTPVØ(I)	Temperature array for oxidizer vapor pressure array. Enter NPVAPØ values. Units: °R.
900,910* (6E12.8)	TPVAPØ(I)	Oxidizer vapor pressure array corresponding with TTPVØ temperature array. Units: psia
		BØIL and IGN Propellant Data (Card 920. Include when JBØIL≠0 or JIGN≠0)
920 (6E12.8)	TDFPF	Fuel freezing point temperature. Units: °R.
	CPLF	Fuel liquid specific heat. Units: Btu/lb_m-°R.
	TDFPØ	Oxidizer freezing point temperature. Units: °R
	CPLØ	Oxidizer liquid specific heat. Units: Btu/lb_m-°R.
		IGN Propellant Data (Cards 930-980. Include when JIGN≠0)
930 (6E12.8)	CPSF	Fuel solid specific heat. Units: Btu/lb_m-°R.
	CPVF	Fuel vapor specific heat. Units: Btu/lb_m-°R.
	MUVF	Fuel vapor viscosity. Units: lb_m/ft-sec.
	KCF	Fuel vapor thermal conductivity. Units: Btu/sec-ft^2-°R/ft.
	LMBDSF	Fuel latent heat of sublimation. Units: Btu/lb_m.
	LMBDFF	Fuel latent heat of fusion. Units: Btu/lb_m.
940 (6E12.8)	ALPHAF	Fuel accommodation coefficient.
	STENF	Fuel surface tension. Units: lb_f/ft.
950 (6E12.8)	CPSØ CPVØ MUVØ KCØ LMBDSØ LMBDFØ	Same as on card 930 except for oxidizer parameters.
960 (6E12.8)	ALPHAØ STENØ	Same as on card 940 except for oxidizer parameters.
970 (6E12.8)	ØFINT	Intermediate oxidizer/fuel mass ratio.
	AIINI	Arrhenius pre-exponential factor for intermediate times the molecular weight of the intermediate. Units: cc-gr/g-$mole^2$-sec.
	EINT	Activation energy for intermediate. Units: cal/g-mole.
	AQIGN	Ignition heat release factor. Units: Cal-cc/g-$mole^2$-sec.
	QEXIGN	External heat source for ignition. Units: cal/g-mole.

*Omit or add cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
980 (6E12.8)	DELHRC	Heat of reaction for formation of liquid intermediate. Units: Btu/lb_m.
	DELHRV	Heat of reaction for formation of vapor intermediate. Units: Btu/lb_m.
	TINT	Temperature limit for formation of intermediate. Units: ^oR.
	TCV	Temperature above which vapor intermediate forms. Units: ^oR.
		<u>Engine Balance Data</u> (Cards 1000-1070)
1000 (6I12)	NTYPEB	Type of engine balance: "1" for constant pressures at feed system inlets, "2" for constant injector end pressure, P_{ie}, and propellant injection mixture ratio.
	NDIA	Number of fuel-oxidizer orifice groups.
1010 (2I12, 2E12.8)	NIF	Number of fuel orifices for this group.
	NIØ	Number of oxidizer fuel orificies for this group.
	DIF	Diameter of fuel orifice for this group. Units: in.
	DIØ	Diameter of oxidizer orifice for this group. Units: in.
1020*		Repeat card 1010 for each orifice group.
1030 (6E12.8)	PVALVF	Fuel valve inlet pressure. Units: psia. } Value not used if NTYPEB=2
	PVALVØ	Oxidizer valve inlet pressure. } Value not used if NTYPEB=2
	XMRI	Injection oxidizer/fuel mass flowrate ratio. } Not required for NTYPEB=1, but used as initial estimates if non-zero.
	PIE	Injector end chamber pressure, Units: psia. } Not required for NTYPEB=1, but used as initial estimates if non-zero.
	RPCIN	Injector end/nozzle stagnation pressure ratio. Not required, but used as initial estimate if non-zero.
1040 (6E12.8)	RVAPF	Estimated fraction of fuel flowrate in vapor or gas state at chamber throat. Set equal to "1." for lack of estimate.
	RVAPØ	Same as above except for oxidizer.
	ECSMIX	Estimated mass-weighted c_{th}^* mixing efficiency factor. Set equal to "1." for lack of estimate.
	ECSENR	Energy factor to account for steady-state losses such as heat losses to chamber wall. Value of "1." is for no energy loss.
1050 (6E12.8)	DT	Chamber throat diameter. Units: in.
	RR	Chamber radius ratio of throat wall profile to throat open passage.

* Omit or add cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
1050 Continued	DCHAM	Chamber diameter. Units: in.
	EBTØL	Engine balance tolerance on solution of RVAPF, RVAPO, ECSMIX and RPCIN expressed as allowable changes in predictor-to-corrector values. Suggested value: 0.002.
	EBTØL2	Engine balance tolerance on injection flowrates of fuel and oxidizer for LISP iteration, measured as fraction change in predictor-to-corrector values. Suggested value: 0.05.
1060 (6E12.8)	DLF	Diameter of fuel feed system line. Units: in.
	RFLF	Friction factor for fuel line flow used in form: $$\Delta P_f = \frac{144\ \dot{w}^2}{2\ g_c}\ \frac{R_f}{A^2}.$$ Units: dimensionless. (When $\Delta P_e >> \Delta P_f$, R_f may be 0)
	AMF	Cross-sectional area of fuel manifold at injector orifice entrance. Units: in^2.
	RFMF	Same as RFLF except for fuel manifold.
	RFIF	Same as RFLF except for fuel injection orificies.
	CFIF	Entrance loss coefficient, K, for fuel orificies used in form: $$\Delta P_e = \frac{144\ \dot{w}^2}{2\ g_c \rho}\ K\ (1/A_i^2 - 1/A_m^2).$$ Units: Dimensionless. Option: if negative value, then value $\equiv -\frac{1}{\sqrt{\rho}}\left(\frac{\dot{w}}{\sqrt{\Delta P_{FS}}}\right)_{ref}$ where subscript FS refers to the entire fuel feed system. (Order of magnitude value: $K=2\times10^{-5} \times$ thrust)
1070 (6E12.8)		Same as card 1060 except for oxidizer.
		<u>LISP Subprogram Input Data</u> (Cards 2010-4020. Include when ILISP≠0)
2010,20 (18A4)		Two comment cards describing injector and specific LISP run conditions.
		Note: Mass fluxes in an axial "collection" plane are calculated at each (r,θ) mesh point of a sector. An inner sector, which may coincide with the complete sector, delineates wall and symmetry boundaries. The complete circular cross-section is comprised of either repeating or mirror image inner sectors.
2030 (12I6)	NEL	Number of injector elements included in LISP analysis (≤ 60).
	NRML	Number of equally spaced concentric arcs in (r,θ) "collection" plane mesh system.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
2030 Continued	NTHML	Number of equally spaced angular positions in (r,θ) "collection" plane mesh system. (NTHMLXNRML $\leq$ 400).
	NRWALL	Number of mesh system radial increments from center to chamber wall. ($\leq$ 20).
	NTHR	Index of mesh system right (clockwise) angular boundary of inner sector. ($\geq$ 1).
	NTHL	Index of mesh system left (counter-clockwise) angular boundary of inner sector. ($\leq$ NTHML).
	JSYM	Type of symmetry indicator: "1" for mirror image, "2" for repeating image.
	NRBAFR	Length in number of radial increments of baffle on right (clockwise) boundary.
	NRBAFL	Same for left (counter-clockwise) boundary.
	NLSPEC	Number of separate specifications for defining groups of injector elements. ($\leq$ 10).
	NCRT	Number CRT constant radius, mass flux vs. theta plots.
	IPUN	Indicator for punched card output (in PMSTC/STAPE): "0" for no punched cards. "1" for punched cards.
2040 (12I6)	IPUNR	Index of right (clockwise) boundary for punched card output.
	IPUNL	Same for left (counter-clockwise) boundary.
	KFCRT KØCRT KTCRT KFFCRT	CRT contour plot indicators for fuel, oxidizer and total mass fluxes and reduced fuel fraction, respectively. Enter number of contour levels or "0" for no plot. With a minus sign, contour interval will be rounded-off. ($\leq$ 35. Recommend approx. 12).
2050 (12I6)	IRCRT(I)	Index of radius selected for CRT plot of mass flux vs. theta. Enter NCRT values. Omit card if NCRT=0.
2060 (6E12.8)	DZØM	Chamber diameter at the "collection" plane. Units: in.
	DTHETM	Theta (angular) increment in "collection" plane (r,θ) mesh system. Units: degrees.
	THETAR	Right (clockwise) theta boundary in "collection" plane mesh system. Units: degrees.
	ZØM	Axial (z) coordinated at the "collection" plane. Units: in.
	ZØM2	If non-zero, an axial coordinate of a second "collection" plane. Units: in.
	ZØM3	If both ZØM2 and ZØM3 non-zero, an axial coordinate of a third "collection" plane. Units: in. The collection plane used for the PMSTC analysis is the last non-zero ZØM.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
2070 (6E12.8)	CDBAR	Correlation coefficient used as a multiplier on program calculated mean drop sizes.
		Cards 2010-2080 are a set of specifications for a group of injector elements, and they must be repeated NLSPEC times.
2110 (12I6)	NTYPE	Element type indicator: "1" for unlike doublet, "2" for like doublet, "3" for like doublet pair, "4" for triplet, "5" for pentad (four-on-one), "8" for general element with correlation coefficients supplied by program user.
	NPRØP1	Index of propellant from orifice 1: "1" for fuel, "2" for oxidizer.
	NPRØP2	Same as NPRØP1 except for orifice 2.
	IDBAR	Spray drop size indicator: "0" for calculating from built-in correlations, "1" for user supplied values.
2120 (6E12.8)	DIA1	Diameter of injector orifice(s) 1. Units: in.
	DIA2	Diameter of injector orifice(s) 2. Units: in.
	CDDIA1	Discharge coefficient of orifice(s) 1.
	CDDIA2	Discharge coefficient of orifice(s) 2.
	ZE	Axial distance of injector element impingement point from injector plane. Units: in.
	GAME	Included angle, γ_E, of orifice 1 and 2 axes. Units: degrees.
		Refer to the text for a full description of the orientation of an element's coordinate system expressed in terms of rotation angles (α, β and γ) from a reference coordinate system orientation.
2130 (6E12.8)	BETA	Angle of rotation, β, about the y-axis. Units: degrees.
	GAMMA	Angle of rotation, γ, about the x-axis. Units: degrees.
		The following card, 2140, is to be included for type 3, like doublet pair, elements only.
2140 (6E12.8)	GAMFAN	Included (cant) angle of spray fans. Units: degrees.
	SPFAN	Y-Spacing between doublet pair. Units: in.
	SPEL	X-Spacing between doublet pair. Units: in.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
		Card 2150 is to be included only if IBBAR≠0 or NTYPE > 5.
2150 (6E12.8)	DBAR1	Mass median spray droplet diameter for propellant from injector orifice(s) 1. Units: in.
	DBAR2	Same as above except from injector orifice(s) 2.
		The following cards, 2050-2080, are to be included for type 8 injector elements only.
2160 (6E12.8)	SC11 SC21 SC31 SC41 SC51 SC61	Spray flux distribution correlation coefficients, C_1 through C_6, for propellant from orifice(s) 1. Refer to Equation 9 in the PMPM Final Report.
2170 (6E12.8)	SC12 SC22 SC32 SC42 SC52 SC62	Same as card 2160 except for propellant from orifice(s) 2.
2180	SA1 SB1	Spray flux distribution correlation coefficient exponents, a and b, from propellant orifice(s) 1. Refer to equation 9 in the PMPM Final Report.
	SA2 SB2	Same except for propellant from orifice(s) 2.
		Preceding cards, 2110-2180, are to be repeated for each NLSPEC specification set. Sequence second digit of card number for each specification set, i.e., second set from 2210-2280.
		Data on the following card, 3010, must be entered for each injector element in the LISP analysis.
3010 (I12,3E12.8)	LSPEC	Index of injector element specification. ($1 \leq$ LSPEC $\leq$ NLSPEC)
	RADE	Chamber radial coordinate, r_E, of injector element impingement point. Units: in.
	THETAE	Chamber angular coordinates θ_E, of injector element impingement point. Units: degrees.
	ALFA	Angle of rotation, α, about the Z-axis used in defining the orientation of an injector element coordinate system with a reference orientation. Units: degrees.
3020-4000* (I12,3E12.8)	LSPEC RADE THETAE ALFA	Same as card 3010 except for next injector element. NEL cards required.

* Add or omit cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
		The following cards, 4010 and 4020, are included only if KFCRT, KØCRT, KTCRT or KFFCRT ≠ 0.
4010 (6E12.8)	W1F W2F W1Ø W2Ø W1T W2T	Minimum and maximum values for contour plots of fuel, oxidizer and total mass fluxes, respectively. Options: W2 = W1, finds max & min values from arrays, W2 < W1, finds max value from array.
4020 (6E12.8)	W1FF W2FF	Same except for reduced fuel fraction. (Range: 0 to 1.)
		PMSTC Subprogram Input Data (Cards 5010-5840. Include when ISTC≠0)
5010 (6I12)	NØZØN NSTPZ	Axisymmetric stream tubes are formed from the LISP (r,θ) mass flux data. After removing a specified fraction of flowrate for the wall boundary stream tube, the remaining flowrate is separated into NØZØN radial zones of approximately equal mass flow rate. NSTPZ is the number of stream tubes formed per zone. Recommended values: NØZØN = 1,2, or 3; NSTPZ ≥ 6. Limit: NØZØNXNSTPZ = 18.
	NGT	Number of spray drop size groups. Set = 12 if ILISP≠0.
	NGF	Number of fuel drop size groups, Set = 6 if ILISP≠0.
	NP	Number of equally spaced axial stations for stepwise calculations between and including start and throat planes. Maximum number of stations, including up to 25 downstream of the throat, is 300.
	NAP	Number of points used to define chamber geometry. (≤ 12)
5020 (6I12)	NSSTI	Maximum number of complete passes, marching from start plane to throat plane in single stream tube analysis, allowed for converging within a tolerance on the solution.
	NMSTI	Maximum number of complete and partial passes marching down the chamber, in multiple stream tube analysis allowed for converging within a tolerance on the solution.
	ICRC	Number of corrector cycle passes at each axial station. (normally = 1).
	IPRSST	Axial-station print interval of single stream tube data.
	IPRMST	Same except for multiple stream tube data.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
5030,40* (6E12.8)	APROF(I,J)	Combustion chamber wall profile data points specified with NAP data pairs of axial distance from injector and diameter, respectively. Set first value (axial distance) = 0. Last data point must be for throat. Chamber wall profile between next-to-last and last points is constructed with radius ratio (RR input on card 1050) at throat and a tangent line. Units: both in inches.
5050 (6E12.8)	DEXIT	Chamber nozzle exit diameter. Units: in.
	PAMB	Ambient pressure at which nozzle flow is discharged. Units: psia.
	ECFVAC	Rocket engine thrust coefficient efficiency, η_{C_F}. Units: dimensionless.
	ZSTART	Axial, z, start plane for stream tube combustion analysis. Units: in.
	ZIMPF	Mean axial, z, location of fuel impingement point(s). Units: in.
	ZIMPØ	Same as preceding for oxidizer.
5060 (6E12.8)	CRTØL	Allowable tolerance on the deviation of computed contraction ratio from unity at chamber throat.
		The following cards, 5100-5120*, are included only when PMSTC is not preceded with LISP. Data represents stream tube conditions at ZSTART.
5100 (6I12)	NST	Number of stream tubes. (≤ 19).
	NASEG	Number pie segments (sectors) required to represent the complete cross-section of chamber. Used as a multiplier on areas, flowrates, etc.
5110* (6E12.8)		Data on this card is for stream tube 1 at ZSTART.
	AREA1(1)	Cross-sectional area. Units: in^2.
	GASFL(1)	Gas flowrate. Units: lb_m/sec.
	SMRG(1)	Gas mixture ratio (oxidizer/fuel flowrates).
	SNN(1)	Number of LISP mesh points. Entry may be left blank.
	SR(1)	Mean radius. Units: in.
	STH(1)	Angular position. Leave blank.

* Add or omit cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
5120* (6E12.8)		Data on this card is for spray group 1 and 2 in stream tube 1 at ZSTART.
	GWSPR(1,1)	Flowrate of group 1 propellant spray. Units: lb_m/sec.
	GVELD1(1,1)	Velocity of group 1 propellant spray. Units: ft/sec.
	GDIAD1(1,1)	Diameter of group 1 propellant spray. Units: in.
	GWSPR(2,1) GVELD(2,1) GDIAD1(2,1)	Same as preceding except for group 2 propellant spray.
		Data on card 5120 is required for each of the NGT propellant spray groups in the stream tube.
		Data on card 5110 along with the propellant spray group data on card 5120 for each of NGT groups must be entered NST times.
		Option in LISP allows punching of data listed for card 5110 and 5120.
		TDK Subprogram Input Data (Cards 5800-5840; Include when ITDK≠0)
		The start line data arrays are setup and punched on cards in PMSTC. If TDK is not immediately preceded by PMSTC, these data must either be input via namelist (See "long form" option in TDK manual) or by using the punched cards with the auxiliary TDK control program. In either case, the following data must be supplied in addition.
5800,10,20*		Namelist Name: PRØPEL
(Namelist)	RSTAR	Throat radius. Units: in.
	EC	Chamber contraction ratio.
	RWT	Wall radius of curvature at throat/throat radius.
	RI	Wall radius of curvature at beginning of convergence/throat radius.
	THETAI	Wall convergence half angle. Units: degrees.
	THETA	Wall angle at downstream end of throat wall radius. Units: degrees.
	FMØL(N)	Number of moles of element N in 100g.

N	Element	Molecular Weight
1	Carbon	12.011
2	Hydrogen	1.008
3	Oxygen	16.000
4	Chlorine	35.457
5	Fluorine	19.000
6	Nitrogen	14.008

* Add or omit cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
5800,10,20 Continued	ØXMØL(N)	Number of moles of element N in 100g of oxidizer.
	HF(1)	Enthalpy of fuel. Units: cal/g.
	HF(2)	Enthalpy of oxidizer. Units: cal/g.
5830,40* Namelist		Namelist Name: DATA.
	IWALL	Wall contour indicator. Set = 1. Other options listed in TDK manual.
	RRT	Wall radius of curvature of downstream side of throat/ throat radius.
	THJ	Exit cone half angle. Units: degrees.
	EPS	Expansion area ratio.
	N1	Print interval of calculations for interior points along characteristic lines selected for print.
	N2	Print interval of calculations for characteristic lines.
	IMAX	Limit on iterations for convergence. 15 recommended.
	IMAXF	Termination indicator if IMAX not sufficient. "1" to terminate. Recommend "0" to continue.
		PULSE Subprogram Input Data (Cards 6010-6630. Include when IPULSE≠0)
6010 (6I12)	NSPACE	Number of pulses in sequence of "standard" width pulses with spacing (off-time) as a parameter (≤ 12).
	NTWALL	Number of sequences of "standard" width pulses with chamber wall temperature effect on boil-off as a parameter. (≤ 6).
	IIGN	Ignition model indicator: "1" to envoke, "0" to bypass.
	IBØIL	Same except for boil-off model.
	IPPRT	Print indicator for which each level adds to printout: "0" for no transient printout, "1" for regular transient (2 lines per Δt)printout, "2" for feed system data from FLØW and BØIL, "3" for dynamic flow solution data from FLØW. Normal value is 1,with 2 and 3 used for checkout only.
	ICRTP	CRT plot indicator: "1" to plot thrust and flowrate traces, "0" to omit.
6020 (6E12.8)	DTMS	Time step for transient calculations. Units: msec.
	STDPW	Pulse width (on-time) for "standard" pulses. Should be long enough for transients to decay and as short as possible to minimize computer execution time. Units: msec.
	TAMB	Ambient temperature for initial chamber temperature. Units: ^{o}R.
	PAMB	Ambient pressure at which nozzle flow discharges. Units: psia.
	[illegible]	Temperature of oxidizer entering feed system. Units: ^{o}R.

* Add or omit cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
6020 Continued	TLF	Temperature of fuel entering feed system. Units: ^{o}R.
6030 (6E12.8)	VVALF	Fuel valve applied voltage. Units: volts.
	VVALØ	Oxidizer valve applied voltage. Units: volts.
	CØEHTH	Exponential coefficient for chamber wall heating during continuous firing.
	CØEHTC	Exponential coefficient for cooling chamber walls while chamber is off.
	TAUIGC	Ignition delay constant, τ_{ign}. Units: msec.
	TCWSS	Steady-state thrust chamber wall temperature Units: ^{o}R.
6040 (6E12.8)	QSBFSS	Steady-state heat soak-back from fuel feed system to propellant. Units: Btu/sec.
	QSBØSS	Same except for oxidizer.
	TFSBF	Steady-state oxidizer feed system temperature. Units: ^{o}R
	TFSBØ	Same except for fuel.
6050,60 (6E12.8)	PSPACE(I)	Pulse spacing (off-time) array. Enter NSPACE values. Units: msec.
6070 (6E12.8)	TTWALL(J)	Chamber wall temperature array. Enter NTWALL values ranging from ambient to steady-state values. Units: ^{o}R.
6100 (6I12)	NTVEF	Array size for fuel valve opening table of fraction open area vs. elapsed time from valve coil de-energization (≤ 9).
	NTVDEF	Array size for fuel valve closing table of fraction open area vs. elapsed time from value coil de-energization (≤ 9).
	NTVEØ	Same as NTVEF except for oxidizer valve.
	NTVDEØ	Same as NTVDEF except for oxidizer valve.
6110* (6E12.8)	TTVEF(I)	Time array for fuel valve opening table. Enter NTVEF values. Units: msec.
6120* (6E12.8)	TAVEF(I)	Fraction open area array for fuel valve opening table. Enter NTVEF values.
6130* (6E12.8)	TTVDEF(I)	Time array for fuel valve closing table. Enter NTVDEF values. Units: msec.
6140* (6E12.8)	TAVDEF(I)	Fraction open area array for fuel valve closing table. Enter NTVDEF values.
6150* (6E12.8)	TTVEØ(I)	Same as TTVEF except for oxidizer table.

* Add or omit cards as case requires.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
6160* (6E12.8)	TAVEØ(I)	Same as TAVEF except for oxidizer table.
6170* (6E12.8)	TTVDEØ(I)	Same as TTVDEF except for oxidizer table.
6180* (6E12.8)	TAVDEØ(I)	Same as TAVDEF except for oxidizer table.
6190 (6E12.8)	AVEF	Fuel valve full open area. Units: in^2.
	CFVF	Entrance loss coefficient, K, for partially open fuel value used in form: $$\Delta P = \frac{144\,\dot{w}^2}{2\,g_c\,\rho}\;K\left(\frac{1}{A(t)^2} - \frac{1}{A^2_{open}}\right).$$ Units: dimensionless.
	AOVEF A1VEF	Coefficients a_o and a_1 for fuel valve energize time calculation: $t_e = a_o + a_1 v$. Units of t: msec.
	AOVDEF A1VDEF	Same as preceding except for valve de-energize time.
6200 (6E12.8)	AVEØ CFVØ AOVEØ A1VEØ AOVDEØ A1VDEØ	Same as card 6190 except for oxidizer valve.
6210 (6E12.8)	LLF	Fuel feed system line length. Units: in. (>0.)
	LLØ	Oxidizer feed system line length. (>0.)
	VØLMF	Fuel manifold volume. Units: in^3. (>0.)
	VØLMØ	Oxidizer manifold volume. (>0.)
	LIF	Mean length of fuel injector orifice(s). Units: in. (>0.)
	LIØ	Mean length of oxidizer injector orifice(s). (>0.)
		Cards 6300-6500 are included only if PULSE is not preceded by PMSTC in the same computer run. (ISTC≠0)
6300 (6E12.8)	VØLC	Combustion chamber volume. Units: in^3.
	LCHAM	Chamber length. Units: in.
	AEXIT	Chamber nozzle exit area: in^2.
	AWCHAM	Chamber wall area. Used in IGN only. Units: in^2.
	DIMPF	Fuel injection impingement distance from injector. Units: in.
	DIMPØ	Oxidizer injection impingement distance from injector. Units: in.

* Add or omit cards as case requires

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
6310 (6E12.8)	ECFVAC	Thrust coefficient efficiency in vacuum.
	WGCHAM	Weight of gas in chamber during steady-state operation. Units: lbm.
6321-6329 by 10 (6E12.8)	TR(I)	Time array for the depletion of propellant spray ensembles. Enter 50 equally incremented times. These data are punched when PMSTC is executed. Units: msec.
6330-6338 by 10 (6E12.8)	SPRAYF(I)	Depletion (resulting from gasification) array for a fuel spray ensemble corresponding with the TR time array, expressed as a fraction of original spray ensemble mass as a function of elapsed time from the instant of impingement.
6339-6347 by 10 (6E12.8)	SPRAYØ(I)	Same as SPRAYF except for oxidizer ensemble.
		Include cards 6600-6630 only if IGN is executed. (IIGN≠0)
6600 (6E12.8)	LIWF	Mean path length of fuel drop from inector to chamber wall. Units: ft.
	LITF	Mean path length of fuel drop from injector to thoat. Units: ft.
	LIWØ	Same as LIWF except for oxidizer.
	LITØ	Same as LITØ except for oxidizer.
6610 (6I12)	LF LØ LIF LIØ	Number of passes for looping on fuel and oxidizer sections of program. Set all of them = 1.
6620 (6E12.8)	TMAX	Maximum simulated time allowed to attain ignition. Units: msec (8.)*
	DPRT	Increment on simulated time for pringing output. Units: msec. (8.)*
	THTF	Time interval during which fuel drop-chamber wall, heat transfer factor changes from maximum to minimum value. Units: sec. (0.002)*.
	FMAXF FMINF	Maximum and minimum fuel drop/chamber wall heat transfer factor, respectively. Units: dimensionless. (0.125 & 0.01)*.
	THTØ	Same as THTF except for oxidizer.
6630 (6E12.8)	FMAXØ FMINØ	Same as FMAXF & FMINF, respectively, except for oxidizer. (0.25 & 0.02)*.
	DTSMS	IGN calculation time interval. Units: msec.

* Values used in Seamans' sample case.

TABLE 1. SPECIFICATION OF INPUT DATA (Continued)

CARD NO. AND FORMAT	VARIABLE CODE	DESCRIPTION
		DCYCLE Input Data (Cards 7400-7440. Include when IDCYCL≠0)
		If DCYCLE is not preceded in same computer run by PULSE, data cards punched by PULSE must be inserted here.
7400,10 (18A4)		Two comment cards describing duty cycle case.
7420 (I12, 5E12.8)	NSEQ	Number of pulse sequences in duty cycle.
	ECFQ	Thrust correlation coefficient used in calculating a total impulse adjustment variable which is dependent on chamber wall temperature.
7430 (2I12, 4E12.8)	NPS	Number of pulses in first pulse sequence.
	JPAGE	Print control indicator for full page output. "0" to suppress, "1" for first pulse only, "2" for first and last pulse, "3" for first, center and last pulse, "4" for all pulses. "5" Same as "3", but also deletes all short format printout.
	PWIDTH	Pulse width (duration). Units: msec.
	ØFFB	"Off-time" (spacing) between pulses. Units: msec.
	ØFFC	"Off-time" between last pulse and next sequence For last sequence, enter maximum time in PSPACE array. Units: msec.
7440*	NPS JPAGE PWIDTH ØFFB	Same as card 7430 except for 2nd pulse sequence. Provide separate card for each of NSEQ pulse sequences.
		END OF PMPM INPUT DATA

* Add or omit cards as case requires.

TABLE 2 . INPUT DATA WORK SHEETS

Column	NUMBER	DESCRIPTION
1		1ST PMPM
13		COMMENT CARD
25		
37		
49		
61		
	18A4 73	1 0 80
1		2ND PMPM
13		COMMENT CARD
25		
37		
49		
61		
	18A4 73	2 0 80
1		3RD PMPM
13		COMMENT CARD
25		
37		
49		
61		
	18A4 73	3 0 80
1		4TH PMPM
13		COMMENT CARD
25		
37		
49		
61		
	18A4 73	4 0 80
1		ILISP
13		ISTC
25		ITDK
37		IPULSE
49		IDCYCL
61		
	6I12 73	5 0 80
1		JLISP
13		JSTC
25		JPULSE
37		JBØIL
49		JIGN
61		
	6I12 73	6 0 80
1		PROPELLANT TITLE CARD
13		
25		INCLUDE ONLY IF
37		JLISP≠0 or JSTC≠0 or
49		JPULSE≠0
61		
	18A4 73	9 0 80
1		
13		
25		
37		
49		
61		
	73	80

TABLE 2. (Continued)

Include these cards if JLISP≠0 or JSTC≠0 or JPULSE≠0

Col.	NUMBER	DESCRIPTION
1		NMR
13		NMACH
25		NEPS
37		NTK
49		
61		
	6I12 (73)	1 0 0 (80)

Col.	NUMBER	DESCRIPTION
1		TMR(I),I=1,NMR
13		
25		
37		
49		
61		
	6E12.8 (73)	1 1 1 (80)

Col.	NUMBER	DESCRIPTION
1		TMR(I)
13		Con't.
25		
37		Include card if NMR > 6
49		
61		
	6E12.8 (73)	1 1 2 (80)

Col.	NUMBER	DESCRIPTION
1		TMR(I)
13		Con't.
25		
37		Include card if NMR > 12
49		
61		
	6E12.8 (73)	1 1 3 (80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

TABLE 2. (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

Col.	NUMBER	DESCRIPTION
1		TMACH(I),
13		I=1,NMACH
25		
37		
49		
61		
	6E12.8 (73)	1 2 0 (80)

Col.	NUMBER	DESCRIPTION
1		TSTAT(I)
13		I=1, NMR
25		FOR M=TMACH(I)
37		
49		
61		
	6E12.8 (73)	2 1 1 (80)

Col.	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	2 1 2 (80)

Col.	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	2 1 3 (80)

Col.	NUMBER	DESCRIPTION
1		TVIS(I,1),
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 (73)	2 2 1 (80)

Col.	NUMBER	DESCRIPTION
1		TVIS(I,1)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	2 2 2 (80)

Col.	NUMBER	DESCRIPTION
1		TVIS(I,1)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	2 2 3 (80)

Col.	NUMBER	DESCRIPTION
1		TGAM(I,1)
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 (73)	2 3 1 (80)

TABLE 2 (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

Column	Number	Description	Card
1–72	6E12.8	TGAM(I,1) CONT.	2 3 2
1–72	6E12.8	TGAM(I,1) CONT.	2 3 3
1–72	6E12.8	TMW(I,1), I=1, NMR	2 4 1
1–72	6E12.8	TMW(I,1) CONT.	2 4 2
1–72	6E12.8	TMW(I,1) CONT.	2 4 3
1–72	6E12.8	TVSØN(I), I=1, NMR FOR M=TMACH(1)	2 5 1
1–72	6E12.8	TVSØN(I) CONT.	2 5 2
1–72	6E12.8	TVSØN(I) CONT.	2 5 3

TABLE 2 . (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

Column	NUMBER	DESCRIPTION
1		TSTAT(I)
13		I=1,NMR
25		FOR M=TMACH(2)
37		
49		
61		
	6E12.8 73	3 1 1 80

Column	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	3 1 2 80

Column	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	3 1 3 80

Column	NUMBER	DESCRIPTION
1		TVIS(I,2),
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 73	3 2 1 80

Column	NUMBER	DESCRIPTION
1		TVIS(I,2)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	3 2 2 80

Column	NUMBER	DESCRIPTION
1		TVIS(I,2)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	3 2 3 80

Column	NUMBER	DESCRIPTION
1		TGAM(I,2)
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 73	3 3 1 80

Column	NUMBER	DESCRIPTION
1		TGAM(I,2)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	3 3 2 80

TABLE 2 . (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

Column	NUMBER	DESCRIPTION
1		TGAM(I,2)
13		CONT.
25		
37		
49		
61		
73	6E12.8	3 3 3

Column	NUMBER	DESCRIPTION
1		TMW(I,2),
13		I=1,NMR
25		
37		
49		
61		
73	6E12.8	3 4 1

Column	NUMBER	DESCRIPTION
1		TMW(I,2)
13		CONT.
25		
37		
49		
61		
73	6E12.8	3 4 2

Column	NUMBER	DESCRIPTION
1		TMW(I,2)
13		CONT.
25		
37		
49		
61		
73	6E12.8	3 4 3

Column	NUMBER	DESCRIPTION
1		TVSØN(I)
13		I=1,NMR
25		FOR M=TMACH(2)
37		
49		
61		
73	6E12.8	3 5 1

Column	NUMBER	DESCRIPTION
1		TVSØN(I)
13		CONT.
25		
37		
49		
61		
73	6E12.8	3 5 2

Column	NUMBER	DESCRIPTION
1		TVSØN(I)
13		CONT.
25		
37		
49		
61		
73	6E12.8	3 5 3

Column	NUMBER	DESCRIPTION
1		TSTAT(I)
13		I=1,NMR
25		FOR M=TMACH(3)
37		
49		
61		
73	6E12.8	4 1 1

TABLE 2 . (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 1 2 80

	NUMBER	DESCRIPTION
1		TSTAT(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 1 3 80

	NUMBER	DESCRIPTION
1		TVIS(I,3)
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 73	4 2 1 80

	NUMBER	DESCRIPTION
1		TVIS(I,3)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 2 2 80

	NUMBER	DESCRIPTION
1		TVIS(I,3)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 2 3 80

	NUMBER	DESCRIPTION
1		TGAM(I,3),
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 73	4 3 1 80

	NUMBER	DESCRIPTION
1		TGAM(I,3)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 3 2 80

	NUMBER	DESCRIPTION
1		TGAM(I,3)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	4 3 3 80

TABLE 2 . (Continued)

Include these cards if JLISP=2 or JSTC≠0 or JPULSE≠0

Col.	NUMBER	DESCRIPTION
1		TMW(I,3),
13		I=1,NMR
25		
37		
49		
61		
	6E12.8	73 4 4 1 80

Col.	NUMBER	DESCRIPTION
1		TMW(I,3)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 4 4 2 80

Col.	NUMBER	DESCRIPTION
1		TMW(I,3)
13		
25		
37		
49		
61		
	6E12.8	73 4 4 3 80

Col.	NUMBER	DESCRIPTION
1		TVSØN(I),
13		I=1,NMR
25		FOR M=TMACH(3)
37		
49		
61		
	6E12.8	73 4 5 1 80

Col.	NUMBER	DESCRIPTION
1		TVSØN(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 4 5 2 80

Col.	NUMBER	DESCRIPTION
1		TVSØN(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 4 5 3 80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
		73 80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
		73 80

TABLE 2 . (Continued)

Include these cards if JLISP≠0 or JSTC≠0 or JPULSE≠0

	NUMBER	DESCRIPTION
1		CSTR(I),
13		I=1,NMR
25		
37		
49		
61		
	6E12.8 73	5 0 1 80

	NUMBER	DESCRIPTION
1		CSTR(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	5 0 2 80

	NUMBER	DESCRIPTION
1		CSTR(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	5 0 3 80

	NUMBER	DESCRIPTION
1		TEPS(I),
13		I=1,NEPS
25		
37		FOR JSTC≠0 &
49		JPULSE≠0 ONLY
61		
	6E12.8 73	5 0 8 80

	NUMBER	DESCRIPTION
1		TCF(I,1),
13		I=1,NMR
25		
37		FOR JSTC≠0 &
49		JPULSE≠0 ONLY
61		
	6E12.8 73	5 1 1 80

	NUMBER	DESCRIPTION
1		TCF(I,1)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	5 1 2 80

	NUMBER	DESCRIPTION
1		TCF(I,1)
13		CONT.
25		
37		
49		
61		
	6E12.8 73	5 1 3 80

	NUMBER	DESCRIPTION
1		TCF(I,2),
13		I=1,NMR
25		
37		FOR JSTC≠0 &
49		JPULSE ≠0 ONLY
61		
	6E12.8 73	5 2 1 80

TABLE 2. (Continued)

Include these cards if JSTC≠0 or JPULSE≠0

NUMBER	DESCRIPTION	73–80
6E12.8	TCF(1,2) CONT.	5 2 2
6E12.8	TCF(1,2) CONT.	5 23
6E12.8	TCF(1,3), I=1,NMR	5 3 1
6E12.8	TCF(1,3) CONT.	5 3 2
6E12.8	TCF(1,3) CONT.	5 3 3
6E12.8	TCF(I,4), I=1,NMR	5 4 1
6E12.8	TCF(1,4) CONT.	5 4 2
6E12.8	TCF(1,4) CONT.	5 4 3

TABLE 2. (Continued)

Include these cards if JLISP≠0 or JSTC≠0 , r JPULSE≠0

Column	NUMBER	DESCRIPTION
1		DENS1
13		DENS2
25		
37		
49		
61		
73 / 80	6E12.8	570

Column	NUMBER	DESCRIPTION
1		PX
13		DNSAX1
25		DNSAX2 JLISP≠0
37		SDNSA1 ONLY
49		SDNSA2
61		CKP1
73 / 80	6E12.8	580

Column	NUMBER	DESCRIPTION
1		CKP2 FOR
13		STEN1 JLISP≠0
25		STEN2 ONLY
37		VISC1
49		VISC2
61		
73 / 80	6E12.8	590

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73 / 80		

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73 / 80		

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73 / 80		

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73 / 80		

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73 / 80		

TABLE 2 . (Continued)

Include these cards if JSTC≠0

Card	Number	Description	Format	Card No.
600		TVF(I) I=1,NTK	6E12.8	6 0 0
610		TVF(I) CONT.	6E12.8	6 1 0
620		CPVAPF(I) I=1,NTK	6E12.8	6 2 0
630		CPVAPF(I) CONT.	6E12.8	6 3 0
640		TCØNVF(I) I=1,NTK	6E12.8	6 4 0
650		TCØNVF(I) CONT.	6E12.8	6 5 0
660		TVØ(I) I=1,NTK	6E12.8	6 6 0
670		TVØ(I) CONT.	6E12.8	6 7 0

TABLE 2 . (Continued)

Include these cards if JSTC≠0 or JPULSE≠0

Column	Number	Description
1		CPVAPØ(I)
13		I=1,NTK
25		
37		FOR
49		JSTC≠0
61		ONLY
	6E12.8	73 6 8 0 80

Column	Number	Description
1		CPVAPØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 6 9 0 80

Column	Number	Description
1		TCØNVØ(I)
13		I=1,NTK
25		
37		FOR
49		JSTC≠0
61		ONLY
	6E12.8	73 7 0 0 80

Column	Number	Description
1		TCØNVØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 7 1 0 80

Column	Number	Description	
1		TNBF	
13		TNBØ	FOR
25		RHØFNB	JSTC≠0
37		RHØØNB	ONLY
49		TCRITF	
61		TCRITØ	
	6E12.8	73 7 2 0 80	

Column	Number	Description	
1		TBF	
13		TBØ	FOR
25		RHØBF	JSTC≠0
37		RHØBØ	ONLY
49			
61			
	6E12.8	73 7 3 0 80	

Column	Number	Description	
1		WTMLLF	FOR
13		WTMLLØ	JSTC≠0
25		WTMLVF	JBØIL≠0
37		WTMLVØ	JIGN≠0
49		DHVF	
61		DHVØ	
	6E12.8	73 7 4 0 80	

Column	Number	Description	
1		NRHØF	
13		NRHØØ	FOR
25		NPVAPF	JPULSE≠0
37		NPVAPØ	ONLY
49			
61			
	6I12	73 7 5 0 80	

TABLE 2 . (Continued)

Include these cards if JPULSE≠0

Column	NUMBER	DESCRIPTION
1		TTRLF(I)
13		I=1,NRHØF
25		
37		
49		
61		
	6E12.8	73 7 6 0 80

Column	NUMBER	DESCRIPTION
1		TTRLF(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 7 7 0 80

Column	NUMBER	DESCRIPTION
1		TRHØF(I)
13		I=1,NRHØF
25		
37		
49		
61		
	6E12.8	73 7 8 0 80

Column	NUMBER	DESCRIPTION
1		TRHØF(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 7 9 0 80

Column	NUMBER	DESCRIPTION
1		TTRLØ(I)
13		‡1,NRHØØ
25		
37		
49		
61		
	6E12.8	73 8 0 0 80

Column	NUMBER	DESCRIPTION
1		TTRLØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 8 1 0 80

Column	NUMBER	DESCRIPTION
1		TRHØØ(I)
13		I=1,NRHØØ
25		
37		
49		
61		
	6E12.8	73 8 2 0 80

Column	NUMBER	DESCRIPTION
1		TRHØØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8	73 8 3 0 80

TABLE 2 . (Continued)

Include these cards if JPULSE≠0

Column	NUMBER	DESCRIPTION
1		TTPVF(I)
13		I=1,NPVAPF
25		
37		
49		
61		
	6E12.8 (73)	8 4 0 (80)

Column	NUMBER	DESCRIPTION
1		TTPVF(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	8 5 0 (80)

Column	NUMBER	DESCRIPTION
1		TPVAPF(I)
13		I=1,NPVAPF
25		
37		
49		
61		
	6E12.8 (73)	8 6 0 (80)

Column	NUMBER	DESCRIPTION
1		TPVAPF(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	8 7 0 (80)

Column	NUMBER	DESCRIPTION
1		TTPVØ(I)
13		I=1,NPVAPØ
25		
37		
49		
61		
	6E12.8 (73)	8 8 0 (80)

Column	NUMBER	DESCRIPTION
1		TTPVØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	8 9 0 (80)

Column	NUMBER	DESCRIPTION
1		TPVAPØ(I)
13		I=1,NPVAPØ
25		
37		
49		
61		
	6E12.8 (73)	9 0 0 (80)

Column	NUMBER	DESCRIPTION
1		TPVAPØ(I)
13		CONT.
25		
37		
49		
61		
	6E12.8 (73)	9 1 0 (80)

TABLE 2. (Continued)

Include these cards if JBØIL≠0 or JIGN≠0

Column	Number	Description	
1		TDFPF	
13		CPLF	
25		TDFPØ	
37		CPLØ	
49			
61			
73	6E12.8	9 2 0	80

Column	Number	Description	
1		CPSF	
13		CPVF	FOR
25		MUVF	JIGN≠0
37		KCF	ONLY
49		LMBDSF	
61		LMBDFF	
73	6E12.8	9 3 0	80

Column	Number	Description	
1		ALPHAF	
13		STENF	
25			
37		FOR JIGN≠0	
49		ONLY	
61			
73	6E12.8	9 4 0	80

Column	Number	Description	
1		CPSØ	
13		CPVØ	FOR
25		MUVØ	JIGN≠0
37		KCØ	ONLY
49		LMBDSØ	
61		LMBDFØ	
73	6E12.8	9 5 0	80

Column	Number	Description	
1		ALPHAØ	
13		STENØ	
25			
37		FOR JIGN≠0	
49		ONLY	
61			
73	6E12.8	9 6 0	80

Column	Number	Description	
1		ØFINT	
13		AIIMI	FOR
25		EINT	JIGN≠0
37		AQIGN	ONLY
49		EIGN	
61		QEXIGN	
73	6E12.8	9 7 0	80

Column	Number	Description	
1		DELHRC	
13		DELHRV	FOR
25		TINT	JIGN≠0
37		TCV	ONLY
49			
61			
73	6E12.8	9 8 0	80

Column	Number	Description	
1			
13			
25			
37			
49			
61			
73			80

TABLE 2 . (Continued)

Include these cards if ILISP≠0 or ISTC≠0 or IPULSE≠0

Column	Number	Description
1		NTYPEB
13		NDIA
25		
37		
49		
61		
Format (73)	6I12	1 0 0 0 (80)

Column	Number	Description
1		NIF
13		NIØ
25		DIF
37		DIØ
49		
61		
Format (73)	2I12,2E12.8	1 0 1 0 (80)

Column	Number	Description
1		NIF
13		NIC
25		DIF
37		DIØ
49		
61		
Format (73)	2I12,2E12.8	1 0 2 0 (80)

Column	Number	Description
1		PVALVF } FOR
13		PVALVØ } NTYPEB=1
25		XMRI } FOR NTYPEB=2
37		PIE } ~~OR EST. FOR~~ NTYPEB=1 IF ≠0.
49		RPCIN Opt. (≠0.) init. val.
61		
Format (73)	6E12.8	1 0 3 0 (80)

Column	Number	Description
1		RVAPF } BEST EST.
13		RVAPØ } OR
25		ECSMIX } SET=1.
37		ECSENR
49		
61		
Format (73)	6E12.8	1 0 4 0 (80)

Column	Number	Description
1		DT
13		RR
25		DCHAM
37		EBTØL
49		EBTØL2
61		
Format (73)	6E12.8	1 0 5 0 (80)

Column	Number	Description
1		DLF
13		RFLF
25		AMF
37		RFMF
49		RFIF
61		CFIF
Format (73)	6E12.8	1 0 6 0 (80)

Column	Number	Description
1		DLØ
13		RFLØ
25		AMØ
37		RFMØ
49		RFIØ
61		CFIØ
Format (73)	6E12.8	1 0 7 0 (80)

TABLE 2 . (Continued)

Include these cards if ILISP≠0

Col	Number	Description	
1		1st LISP	
13		COMMENT	
25		CARD	
37			
49			
61			
	18A4	73	2 0 1 0 80

Col	Number	Description	
1		2nd LISP	
13		COMMENT	
25		CARD	
37			
49			
61			
	18A4	73	2 0 2 0 80

Col	Number	Description	
1		NEL	NRML
13		NTHML	NRWALL
25		NTHP	NTHL
37		JSYM	NRBAFR
49		NRBAFL	NLSPEC
61		NCRT	IPUN
	12I6	73	2 0 3 0 80

Col	Number	Description	
1		IPUNR	IPUNL
13		KFCRT	KØCRT
25		KTCRT	KFFCRT
37			
49			
61			
	12I6	73	2 0 4 0 80

Col	Number	Description
1		IRCRT(I)
13		I=1,NCRT
25		
37		(OMIT IF
49		NCRT ≤ 0)
61		
	12I6 73	2 0 5 0 80

Col	Number	Description
1		DZØM
13		DTHETM
25		THETAR
37		ZØM
49		ZØM2
61		ZØM3
	6E12.8 73	2 0 6 0 80

Col	Number	Description
1		CDBAR
13		
25		
37		
49		
61		
	6E12.8 73	2 0 7 0 80

Col	Number	Description
1		
13		
25		
37		
49		
61		
	73	80

TABLE 2. (Continued)

Include these cards if ILISP≠0. Provide set of cards (2_10 to 2_80) for each element specification.

Col.	NUMBER	DESCRIPTION	
1		NTYPE	NPRØP1
13		NPRØP2	IDBAR
25			
37			
49			ELEM. SPEC.
61			
	12I6	73	2 1 0 80

Col.	NUMBER	DESCRIPTION
1		DIA1
13		DIA2
25		CDDIA1
37		CDDIA2
49		ZE
61		GAME
	6E12.8 73	2 2 0 80

Col.	NUMBER	DESCRIPTION
1		BETA
13		GAMMA
25		
37		
49		
61		
	6E12.8 73	2 3 0 80

Col.	NUMBER	DESCRIPTION
1		GAMFAN
13		SPFAN
25		SPEL
37		
49		(FOR NTYPE=3, ONLY)
61		
	6E12.8 73	2 4 0 80

Col.	NUMBER	DESCRIPTION
1		DBAR1
13		DBAR2
25		
37		FOR IDBAR = Ø ONLY
49		
61		
	6E12.8 73	2 5 0 80

Col.	NUMBER	DESCRIPTION	
1		SC11	
13		SC21	(FOR
25		SC31	NTYPE=8
37		SC41	ONLY)
49		SC51	
61		SC61	
	6E12.8 73	2 6 0 80	

Col.	NUMBER	DESCRIPTION	
1		SC12	
13		SC22	(FOR
25		SC32	NTYPE=8)
37		SC42	
49		SC52	
61		SC62	
	6E12.8 73	2 7 0 80	

Col.	NUMBER	DESCRIPTION	
1		SA1	(FOR
13		SB1	NTYPE=8
25		SA2	ONLY)
37		SB2	
49			
61			
	6E12.8 73	2 8 0 80	

TABLE 2 . (Continued)

Include these cards if ILISP≠0. One card for each element.

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		Add Seq. No.
	I12,5E12.8 73	3 1 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12,5E12.8 73	3 2 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12,5E12.8 73	3 3 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12,5E12.8 73	3 4 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12, 5E12.8 73	3 5 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12, 5E12.8 73	3 6 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12, 5E12.8 73	3 7 0 80

Column	NUMBER	DESCRIPTION
1		LSPEC
13		RADE
25		THETAE
37		ALFA
49		
61		
	I12, 5E12.8 73	3 8 0 80

TABLE 2 . (Continued)

Include these cards if ILISP≠0

Column	NUMBER	DESCRIPTION	
1		W1F	FOR
13		W2F	KFCRT≠0
25		W1Ø	KØCRT≠0
37		W2Ø	KTCRT≠0
49		W1T	OR
61		W2T	KFFCRT≠0
	6E12.8	73 4010 80	

Column	NUMBER	DESCRIPTION	
1		W1FF	FOR
13		W2FF	KFCRT≠0
25			KØCRT≠0
37			KTCRT≠0
49			OR
61			KFFCRT≠0
		73 4020 80	

TABLE 2 . . (Continued)

Include these cards if ISTC≠0

Col.	NUMBER	DESCRIPTION
1		NØZØN
13		NSTPZ
25		NGT
37		NGF
49		NP
61		NAP
	6I12 (73)	5 0 1 0 (80)

Col.	NUMBER	DESCRIPTION
1		NSSTI
13		NMSTI
25		ICRC
37		IPRSST
49		IPRMST
61		
	6I12 (73)	5 0 2 0 (80)

Col.	NUMBER	DESCRIPTION	
1		APRØF(1,1)	$Z_1=0.$
13		APRØF(1,2)	DIA_1
25		APRØF(2,1)	Z_2
37		APRØF(2,2)	DIA_2
49		APRØF(3,1)	Z_3
61		APRØF(3,2)	DIA_3
	6E12.8 (73)	5 0 3 0 (80)	

Col.	NUMBER	DESCRIPTION	
1		APRØF(4,1)	Z_4
13		APRØF(4,2)	DIA_4
25		(NAP PAIRS)	
37			
49			
61			
	6E12.8 (73)	5 0 4 0 (80)	

Col.	NUMBER	DESCRIPTION
1		DEXIT
13		PAMB
25		ECFVAC
37		ZSTART
49		ZIMPF
61		ZIMPØ
	6E12.8 (73)	5 0 5 0 (80)

Col.	NUMBER	DESCRIPTION
1		CRTØL
13		
25		
37		
49		
61		
	6E12.8 (73)	5 0 6 0 (80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	6E12.8 (73)	(80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

TABLE 2. (Continued)

Include these cards if ISTC≠0 and ILISP = 0

Col	NUMBER	DESCRIPTION
1		NST
13		NASEG
25		
37		
49		
61		
73	6I12	5100

Col	NUMBER	DESCRIPTION
1		AREAI(J)
13		GASFL(J)
25		SMRG(J)
37		SNN(J)
49		SR(J) Jth STREAM
61		STH(J) TUBE
73	6E12.8	5110

Col	NUMBER	DESCRIPTION
1		GWSPR(I,J)
13		GVELDI(I,J)
25		GDIADI(I,J)
37		GWSPR(I+1,J)
49		GVELDI(I+1,J)
61		GDIADI(I+1,J)
73	6E12.8	5120

Col	NUMBER	DESCRIPTION
1		CONT. FOR
13		I=1,NGT SPARY GROUPS
25		
37		THEN START NEXT STREAM
49		TUBE ON NEW CARD - J=1,NST
61		
73		

Col	NUMBER	DESCRIPTION
1		
13		ARRAYS ON CARD 5110 &
25		5120 PUNCHED IN STC IF
37		PRECEEDED BY LISP
49		
61		
73		

TABLE 2 . (Continued)

Include these cards if ITDK≠0. Requires NAME LIST FORMAT.

Col.	NUMBER	DESCRIPTION
1	&PRØPEL FM	
13	ØL = ,	
25	, RST	
37	AR = , HF =	
49	,	
61	, JF =	
73	00000580,	80

Col.	NUMBER	DESCRIPTION
1	RI =	
13	EC = , THET	
25	AI = , THE	
37	TA = ,	
49	RWT =	
61	, JF =	
73	00000581,	80

Col.	NUMBER	DESCRIPTION
1	ØXMØL( ) =	
13		
25		
37		
49		
61	JF = 0, &END	
73	00000582 0	80

Col.	NUMBER	DESCRIPTION
1	&DATA IWAL	
13	L = , RRT =	
25	THJ = ,	
37	EPS = ,	
49	NI = , N2 = ,	
61	NC =	
73	00000583,	80

Col.	NUMBER	DESCRIPTION
1	IMAX = ,	
13	IMAXF = ,	
25		
37		
49		
61	NC = &END	
73	00005840	80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73		80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73		80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
73		80

TABLE 2 (Continued)

Include these cards if IPULSE= 1

Column	NUMBER	DESCRIPTION
1		NSPACE
13		NTWALL
25		IIGN
37		IBOIL
49		IPPRT
61		ICRTP
	6I12 (73)	6 0 1 0 (80)

Column	NUMBER	DESCRIPTION
1		DTMS
13		STDPW
25		TAMB
37		PAMB
49		TLØ
61		TLF
	6E12.8 (73)	6 0 2 0 (80)

Column	NUMBER	DESCRIPTION
1		VVALF
13		VVALØ
25		CØEHTH
37		CØEHTC
49		TAUIGC
61		TCVSS
	6E12.8 (73)	6 0 3 0 (80)

Column	NUMBER	DESCRIPTION
1		QSBFSS
13		QSBØSS
25		
37		
49		
61		
	6E12.8 (73)	6 0 4 0 (80)

Column	NUMBER	DESCRIPTION
1		PSPACE(I)
13		I=1,NSPACE
25		
37		
49		
61		
	6E12.8 (73)	6 0 5 0 (80)

Column	NUMBER	DESCRIPTION
1		PSPACE(I)
13		Cont.
25		
37		
49		
61		
	[illegible].8 (73)	6 0 6 0 (80)

Column	NUMBER	DESCRIPTION
1		TTWALL(J)
13		J=1,NTWALL
25		
37		
49		
61		
	6E12.8 (73)	6 0 7 0 (80)

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

TABLE 2 (Continued)

Include these cards if IPULSE=1

	NUMBER	DESCRIPTION
1		NTVEF
13		NTVDEF
25		NTVEØ
37		NTVDEØ
49		
61		
	6I12 73	6 1 0 0 80

	NUMBER	DESCRIPTION
1		TTVEF(I)
13		I=1,NTVEF
25		
37		
49		
61		
	6E12.8 73	6 1 1 0 80

	NUMBER	DESCRIPTION
1		TAVEF(I)
13		I=1,NTVEF
25		
37		
49		
61		
	6E12.8 73	6 1 2 0 80

	NUMBER	DESCRIPTION
1		TTVDEF(I)
13		I=1,NTVDEF
25		
37		
49		
61		
	6E12.8 73	6 1 3 0 80

	NUMBER	DESCRIPTION
1		TAVDEF(I)
13		I=1,NTVDEF
25		
37		
49		
61		
	6E12.8 73	6 1 4 0 80

	NUMBER	DESCRIPTION
1		TTVEØ(I)
13		I=1,NTVEØ
25		
37		
49		
61		
	6E12.8 73	6 1 5 0 80

	NUMBER	DESCRIPTION
1		TAVEØ(I)
13		I=1,NTVEØ
25		
37		
49		
61		
	6E12.8 73	6 1 6 0 80

	NUMBER	DESCRIPTION
1		TTVDEØ(I)
13		I=1,NTVDEØ
25		
37		
49		
61		
	6E12.8 73	6 1 7 0 80

TABLE 2 (Continued)

include these cards if IPULSE=1

Col.	NUMBER	DESCRIPTION
1		TAVDEØ(I)
13		I=1,NTVDEØ
25		
37		
49		
61		
	6E12.8 (73)	6 1 8 0 (80)

Col.	NUMBER	DESCRIPTION
1		AVEF
13		CFVF
25		AOVEF
37		AIVEF
49		AOVDEF
61		AIVDEF
	6E12.8 (73)	6 1 9 0 (80)

Col.	NUMBER	DESCRIPTION
1		AVEØ
13		CFVØ
25		AOVEØ
37		AIVEØ
49		AOVDEØ
61		AIVDEØ
	6E12.8 (73)	6 2 0 0 (80)

Col.	NUMBER	DESCRIPTION
1		LLF
13		LLØ.
25		VØLMF
37		VOLMØ
49		LIF
61		LIØ
	6E12.8 (73)	6 2 1 0 (80)

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	73	80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	73	80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	73	80

Col.	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	73	80

TABLE 2 (Continued)

Include these cards if IPULSE=1 and ISTC=0

Column	NUMBER	DESCRIPTION
1		VØLC
13		LCHAM
25		AEXIT
37		AWCHAM
49		DIMPF
61		DIMPØ
	6E12.8 (73)	6 3 0 0 (80)

Column	NUMBER	DESCRIPTION
1		ECFVAC
13		WGCHAM
25		
37		
49		
61		
	6E12.8 (73)	6 3 1 0 (80)

Column	NUMBER	DESCRIPTION
1		TR(I), I=1,50
13		
25		9 cards punched by STC.
37		
49		
61		
	6E12.8 (73)	6 3 2 0 (80)

Column	NUMBER	DESCRIPTION
1		SPRAYF(I)
13		I=1,50
25		
37		9 cards punched by STC.
49		
61		
	6E12.8 (73)	6 4 1 0 (80)

Column	NUMBER	DESCRIPTION
1		SPRAYØ(I)
13		I=1,50
25		
37		9 cards punched by STC.
49		
61		
	6E12.8 (73)	6 5 0 0 (80)

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

Column	NUMBER	DESCRIPTION
1		
13		
25		
37		
49		
61		
	(73)	(80)

TABLE 2 (Continued)

Include these cards if IPULSE=1 and IIGN 0

Column	NUMBER	DESCRIPTION
1		LIWF
13		LITF
25		LIWØ
37		LITØ
49		
61		
	6E12.8 (73)	6600 (80)

Column	NUMBER	DESCRIPTION
1		LF
13		LIF
25		LØ
37		LIØ
49		
61		
	6I12 (73)	6610 (80)

Column	NUMBER	DESCRIPTION
1		TMAX
13		DPRT
25		THTF
37		FMAXF
49		FMINF
61		THTØ
	6E12.8 (73)	6620 (80)

Column	NUMBER	DESCRIPTION
1		FMAXØ
13		FMINØ
25		DTNMS
37		
49		
61		
	6E12.8 (73)	6630 (80)

TABLE 2 . (Concluded)

Include these cards if IDCYCL=1

Column	NUMBER	DESCRIPTION
1		1st DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A4 (73)	7400 (80)

Column	NUMBER	DESCRIPTION
1		2nd DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A6 (73)	7410 (80)

Column	NUMBER	DESCRIPTION
1		NSEQ
13		
25		
37		
49		
61		
	6I12 (73)	7420 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH Number
37		ØFFB of these
49		ØFFC Cards=NSEQ
61		
	2I12, 4E12.8 (73)	7430 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7440 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7450 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7460 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7470 (80)

TABLE 2. (Concluded)

Include these cards if IDCYCL=1

Column	NUMBER	DESCRIPTION
1		1st DCYCLE
13		Comment
25		Card
37		
49		
61		
73	18A4	7400 (80)

Column	NUMBER	DESCRIPTION
1		2nd DCYCLE
13		Comment
25		Card
37		
49		
61		
73	18A6	7410 (80)

Column	NUMBER	DESCRIPTION
1		NSEQ
13		
25		
37		
49		
61		
73	6I12	7420 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH Number
37		ØFFB of these
49		ØFFC Cards=NSEQ
61		
73	2I12, 4E12.8	7430 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
73	2I12, 4E12.8	7440 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
73	2I12, 4E12.8	7450 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
73	2I12, 4E12.8	7460 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
73	2I12, 4E12.8	7470 (80)

TABLE 2 . (Concluded)

Include these cards if IDCYCL=1

Column	NUMBER	DESCRIPTION
1		1st DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A4 (73)	7 4 0 0 (80)

Column	NUMBER	DESCRIPTION
1		2nd DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A6 (73)	7 4 1 0 (80)

Column	NUMBER	DESCRIPTION
1		NSEQ
13		
25		
37		
49		
61		
	6I12 (73)	7 4 2 0 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH Number
37		ØFFB of these
49		ØFFC Cards=NSEQ
61		
	2I12, 4E12.8 (73)	7 4 3 0 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7 4 4 0 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7 4 5 0 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7 4 6 0 (80)

Column	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7 4 7 0 (80)

TABLE 2 . (Concluded)

Include these cards if IDCYCL=1

	NUMBER	DESCRIPTION
1		1st DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A4 (73)	7400 (80)

	NUMBER	DESCRIPTION
1		2nd DCYCLE
13		Comment
25		Card
37		
49		
61		
	18A6 (73)	7410 (80)

	NUMBER	DESCRIPTION
1		NSEQ
13		EOCF
25		
37		
49		
61		
	I12,5E12.8 (73)	7420 (80)

	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH Number
37		ØFFB of these
49		ØFFC Cards=NSEQ
61		
	2I12, 4E12.8 (73)	7430 (80)

	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7440 (80)

	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7450 (80)

	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7460 (80)

	NUMBER	DESCRIPTION
1		NPS
13		JPAGE
25		PWIDTH
37		ØFFB
49		ØFFC
61		
	2I12, 4E12.8 (73)	7470 (80)

DISCUSSION OF INPUT DATA

This section supplements the description of input data in Table 1. In general, only information relative to those entries which need further explanation for proper usage are discussed here. The discussion is grouped according to the subprograms which read the input data.

PMPMID Input Data

The purpose of this group of input data is to identify the computer run and to specify primary control indicators.

Computer Run Comment Cards. Four comment cards are read and printed for the purpose of identifying the computer run output for future reference. The comments should identify the rocket engine being simulated, nominal operating conditions and purpose of the analysis. The comment cards are printed on a title page which identifies the computer model, including a revision date. The date of the computer run is automatically printed (i.e., if the computer hardware is equipped to do so).

Primary Model Control Indicators. Control indicators provide flexibility in executing PMPM as one complete comprehensive run or individually by major subprogram blocks. Allowable combinations for running subprogram blocks are:

Model Indicator	1	2	3	4	5	6
ILISP	1 or 0	1 or 0	0	1	0	0
ISTC	1	1	0	0	±1	0
ITDK	1 or 0	1 or 0	0	0	0	0
IPULSE	1	0	1	0	0	0
IDCYCL	1 or 0	0	1 or 0	0	0	1

These control indicators are provided to allow flexibility in executing PMPM. Types of situations for which they are useful include:

1. Execution of individual subprograms when the entire model is not required for a particular analysis

2. Bypass subprograms which cannot accommodate a particular case

3. Execute additional cases without rerunning preceeding subprograms

4. Enable the user to evaluate results before proceeding into the next subprogram analysis

Whereas PMPM is fully integrated to execute a complete analysis in a single computer run, execution of the subprograms in sequential runs is generally recommended to enable the user to review the results from one before proceeding to the next. In particular, steady-state performance predicted by LISP and PMSTC should be inspected before proceeding with an expensive TDK run or starting the pulse-mode analysis.

If TDK is included in the analysis, a separate run is recommended using the TDK auxiliary control program and the punched data cards generated by PMSTC. Execution of TDK from PMPM without preceding it with PMSTC in the same run, is undesirable in that the start line data arrays must be manually punched using a namelist format.

Control Indicators for Propellant Properties. In order to limit the input data requirements to those required by the subprograms selected for execution, indicators are read to specify subprograms for which propellant data is supplied. Once a propellant data deck is prepared, it may be convenient to keep it intact even though some parts of it are not required for a particular case. The indicators, being independent of the model selection indicators, allow for this option. Checks are made to terminate the case if insufficient propellant data is requested relative to the subprogram selection indicators.

PPIN Input Data

Propellant property data required by the different subprograms overlap considerably. To eliminate redundancy, all propellant data is read by a single subroutine, PPIN, before executing any of the major subprograms.

Combustion Gas Properties. Combustion gas properties, which must be obtained from prior, peripheral computation using a thermodynamic equilibrium performance computer program, are entered in tabular form as part of the input.

Rocketdyne's free-energy-minimization program has been used here to determine these properties, but any comparable program is adequate. The combustion gas property table is identified in the PMPM printout with a description supplied by the program user on a single input data card. This description should specify the propellants used, the pressure at which the combustion analysis was made and any special information about the combustion analysis. Static, shifting equilibrium properties of temperature, viscosity, molecular weight and sonic velocity, and frozen specific heat ratio, all as functions of both mixture ratio and Mach number, are required in the table. Also theoretical shifting performance of characteristic velocity (c*) as a function of mixture ratio and of thrust coefficient (C_F) as a function of both mixture ratio and nozzle expansion area ratio are required. The mixture ratio array must cover nearly an unlimited range to sufficiently cover typical situations encountered in both LISP and the multiple stream tube section of PMSTC. In order to cover the range from 0 to infinity and to improve the interpolation accuracy, a reduced oxidizer fraction array, bounded by 0 and 1, is constructed internally from the mixture ratio array, c_i, and used thereafter in its place. The normalizing factor is the central value, c_m, from the mixture ratio array, and is used as follows:

$$F'_{o,i} = \frac{c_i}{c_i + c_m}$$

In selecting mixture ratio values for the table, a plot of static temperature vs F'_o, with c_m near the stoichiometric mixture ratio, is helpful in selecting values best suited for linear interpolation.

The Mach number array consists of up to three values. Normally, the values should be 0, a value approximately equal to the Mach number at the beginning of nozzle convergence and 1. If limited to two values, 0 and 1 are recommended. For a single value, a value of 1 is required to obtain a nozzle flowrate corresponding with shifting equilibrium propellant performance.

LISP Saturation Density. Wet bulb density is required in LISP for adjusting spray drop size to account for a change in propellant density from injection to wet bulb conditions. Since wet bulb conditions are not known for input, saturation conditions, which are at a temperature usually only slightly higher than wet bulb, are used instead. Propellant property input data required to calculate saturation density of fuel and oxidizer for specific chamber conditions are saturation densities, DNSAX1 and DNSAX2, at a specified reference pressure, PX, along with their respective slopes, SDNSA1 and SDNSA2, of saturation density with respect to pressure. Pressure has little direct effect on propellant density at constant temperature, but has a significant effect on saturation temperature and the density corresponding with it. The latter effect is the one which must be accounted for.

LISP Evaporation Coefficients. Mean evaporation coefficients CKP1 and CKP2 for fuel and oxidizer, respectively, are used in approximating the partial propellant evaporation in the LISP region of the combustion chamber. Only approximate values can be supplied for these coefficients, and values on the order of 4×10^{-4} may suffice in general. However, for more specific values, the relation should be considered of these coefficients with specific values of the evaporation coefficients calculated in and printed from subprogram PMSTC on previous computer runs. Values of the evaporation coefficients input for use in the LISP region generally should be about 1/4 or 1/5 of those calculated for use in the combustion region in order to account for, in particular, incomplete atomization over the LISP region.

PMSTC Propellant Vapor Properties. Tables of fuel and oxidizer vapor specific heat and thermal conductivity as functions of temperature are required, spanning the range of temperatures across the vapor/combustion gas films around spray droplets. At the lower temperatures, specific heats at constant pressure may be conveniently obtained directly from propellant enthalpy tables or charts. At higher temperatures, dissociation is important and it is appropriate to blend the low temperature, undissociated data into equilibrium dissociation data.

The thermal conductivity needed is not simply that of the vapor, but that of the combustion gas-vapor mixture between a droplet's surface and a surrounding flame-front. Again, a blending between undissociated propellant, dissociated propellant and propellant-rich combustion gases is appropriate at low temperatures with a gradual shift to the conductivity of the combustion gases alone at high temperatures. The general technique used for generating values for these tables is to plot thermal conductivity, calculated from a thermodynamic combustion performance computer model, as a function of combustion gas temperature. Generally, this plots in the form of a loop in which the upper branch corresponds with fuel-rich mixture ratios and the lower branch corresponds with oxidizer-rich mixture ratios. On the same grid, thermal conductivity of the pure vapors are also plotted. Then the conductivity line for the film around a fuel drop is constructed by starting along the fuel vapor line at low temperatures and blending it with the fuel-rich branch of the combustion gas at high temperatures. Likewise for the oxidizer, except blending the oxidizer vapor line with the oxidizer-rich branch.

ENGBAL Input Data

Subroutine ENGBAL performs an engine balance which solves steady-state pressures and flowrates based on best estimates of combustion efficiency. It also performs all its own input and output functions, except for propellant properties.

Types of Engine Balance Solutions. Two types of engine balance solutions may be selected using indicator NTYPEB. Type 1 is for simulating an engine with fixed design parameters in which performance is dependent on the pressures at which the propellants are supplied to the feed system. Type 2 is for a design type analysis in which the chamber injector end pressure and mixture ratio of injected propellant flowrates is specified, letting feed system inlet pressures vary as the case requires.

Injector Orifice Areas. The summation of injector orifice areas is required by ENGBAL for both fuel and oxidizer elements. Input specifications are setup for the program to calculate and sum the areas of circular orifices from diameters and number of orifices. If the injector orifices are not circular, any input combination which will give the same total area is permissible.

Operational Parameters. Input of propellant valve inlet pressures, PVALVF and PVALVØ, is required for type 1 engine balance solution only, since these pressures are solved in ENGBAL for a type 2 solution. The mixture ratio of injected propellant flowrates, XMRI, and injector end pressure are required only for type 2 solutions, but are used if entered as estimated values for type 1 solutions. The program contains logic for predicting the values for XMRI and PIE; however, computational efficiency can be improved by supplying better estimates of these parameters. The ratio of injector end-to-nozzle stagnation pressures is also an optional input, which may improve computational efficiency if a good estimate is known.

Efficiency Factors. Estimate values are required for propellant vaporization efficiencies, RVAPF and RVAPØ, and for gas mixing efficiency, ECSMIX, which is the ratio of mass flowrate weighted theoretical c*'s of individual streamtubes with the theoretical c* at the mean gas mixture ratio at the throat. If no better estimates are available, use values between 0.9 and 1.0. The energy factor, ECSENR, is an input constant which is to be used to account for steady-state losses such as heat transfer from the combustion gases to the chamber wall. Also, this factor is used for projecting losses when the chamber wall is not up to steady-state temperature during a duty cycle analysis. If a value is not well known, ECSENR might be varied for correlating simulated performance with duty cycle test data.

Tolerances on Solution. Satisfactory solution of an engine balance is determined by comparing absolute differences in predicted and corrected values of RVAPF, RVAPØ, ECSMIX and RPCIN with a specified tolerance, EBTØL. Since this is not directly a tolerance on performance, it should be smaller than the accuracy required on the solution of absolute performance. A tolerance of 0.002 was used during checkout and model evaluation without any difficulty, and this value should yield results within approximately 0.005 (0.5%) of a fully converged solution. A second tolerance, EBTØL2, is used as a criteria for making a second pass through both the LISP model and the single stream tube analysis of PMSTC. This may be necessary because mass distribution and mean spray drop sizes are dependent on both the fuel and oxidizer injection flowrates, which are in turn dependent on estimated vaporization and mixing efficiencies and pressure ratio. If the corrected values of injection flowrates deviate significantly, more than EBTØL2, from the predicted values, then both the mass distribution and mean spray drop size analysis and the single stream tube combustion analysis must be updated.

Fluid Flow Resistance Factors. Steady-state pressure losses due to propellant fluid friction in the feed system elements is calculated using the following standard equation for pipe flow:

$$\Delta p_f = \frac{144\ \dot{w}^2}{2 g_c \rho} \frac{R_f}{A^2}$$

where R_f is the friction factor, which is a required data input. The program user may have a better feel for the pressure loss for a reference flow condition than for the friction factor; in which case, R_f may be back-calculated from the foreg g equation.

The equation for the entrance pressure loss of the injector orifices is:

$$\Delta p_e = \frac{144\ \dot{w}^2}{2 g_c \rho}\ K \left(\frac{1}{A_i^2} - \frac{1}{A_m^2}\right)$$

where K in the input entrance loss coefficient. An input option on K exists for the situation in which the injector orifice entrance loss is the primary feed system pressure loss and the entire fuel (or oxidizer) feed system pressure loss, ΔP_{FS}, is known for a reference flow conditi . A negative sign on the input is the indicator for the option, and the absolute value of the input should be:

$$\frac{1}{\sqrt{\rho}} \left(\frac{\dot{w}}{\sqrt{\Delta P_{FS}}}\right)_{ref.}$$

The entrance coefficient is then back-calculated by the program.

LISP Input Data

Subprogram LISP calculates mass distribution and mean spray drop sizes. Parameters for both the injector design and the mesh system for the axial plane in which the mass distribution is calculated (the "collection" plane) must be defined with input data. Spray mass fluxes emitted from injector elements are calculated and summed to obtain the total mass flux at each (r,θ) mesh point in the "collection" plane.

<u>"Collection" Plane Sectors</u>. In order to minimize the number of mesh points required in the "collection" plane and the corresponding number of calculations, the circular cross-sectional area of the chamber at the "collection" plane is split into like sectors as small as symmetry conditions permit. Then calculations are made to analyze a single sector. For plotting, the analysis is extended to cover the complete circular area by considering the symmetry as specified by the JSYM indicator. A mirror image type of symmetry is specified if JSYM=1, and a repeating image if JSYM=2. For completing the circle with mirror image symmetry, a sector for repeating image symmetry is constructed first by joining the analyzed sector with its mirror image. Then the sector for repeating image symmetry is joined together with duplicate sectors to complete the circle. From these considerations, it follows that the defined sector must be an even increment of a half circle for JSYM=1 and an even increment of a whole circle for JSYM=2.

<u>Methods for Analyzing the Sector</u>. One of two methods must be selected for analyzing a sector. The more generally recommended method is to include in the analysis all injector elements which contribute significantly to the sector of concern, including elements outside the angular range of the sector. This is the only valid method for cases where elements are located near the axis of the chamber. The second method is to include only the injector elements within the angular range of the sector and to "collect" all the mass flowrate from these elements, even beyond the angular range of the sector. The mass flowrate "collected" outside the sector is then folded back inside by the program in a manner compatible with the type of symmetry specified. Mass flowrate collected outside a hard boundary, i.e., chamber wall or radial baffle, is folded into the boundary as though the spray had hit the wall upstream and flowed along the wall to the collection plane.

Two sectors are defined in the input, one for the "collection" mesh system and the other for representing an incremental sector of the chamber cross section. These two sectors are sometimes referred to as the outer and inner sectors, respectively, even though the boundaries may coincide. The "collection" sector mesh system contains NRML radial mesh positions and NTHML angular mesh positions. The first angular position corresponds with θ= THETAR. Inner sector boundaries are along the NRWALL radial mesh position and along the NTHR and NTHL angular mesh positions. Generally, the outer sector extends beyond the inner sector in the radial direction to account for spray hitting the wall. The radial boundaries differ only if the second method for analyzing a sector is selected, in which case the flowrate "collected" outside the inner sector is folded back inside.

The number of mesh points in the outer sector is the product of NRML and NTHML. This product is limited to 400 in any combination. For CRT plots, the inner sector is restricted further: NRWALL$\leq$20, (NTHL-NTHR+1)$\leq$20 for JSYM=1 and $\leq$39 for JSYM=2, and the sector angle $\geq 5^{0}$ for JSYM=1 and $\geq 10^{0}$ for JSYM=2.

Spray Drop Sizes. If the injector element is specified as being Type 1 through Type 5, LISP will calculate a mass median drop diameter for the propellant of each orifice of the element. These calculations are based upon correlations derived from hot wax experiments with a liquid physical property correction term, $(\mu \sigma/\rho)$ added. The coefficient CDBAR is a multiplier on these diameters and may be used to correlate, if necessary, results with test data. Alternatively, by assigning a value greater than zero to the indicator IDBAR, the program user assigns his own estimation of drop diameters. For elements defined as Type 8, the user always supplies his own estimation of drop diameter. The appropriate mean droplet diameter is the mass median diameter.

Orientation of an Injector Element's Coordinate System. Individual (x,y,z) coordinate systems are defined for each element with the origins located at the impingement points of the elements. Single impinging element coordinate systems are specified in Fig.10 . For the doublet and triplet elements, the x axis will correspond to the long axis of the spray fan formed by the im-

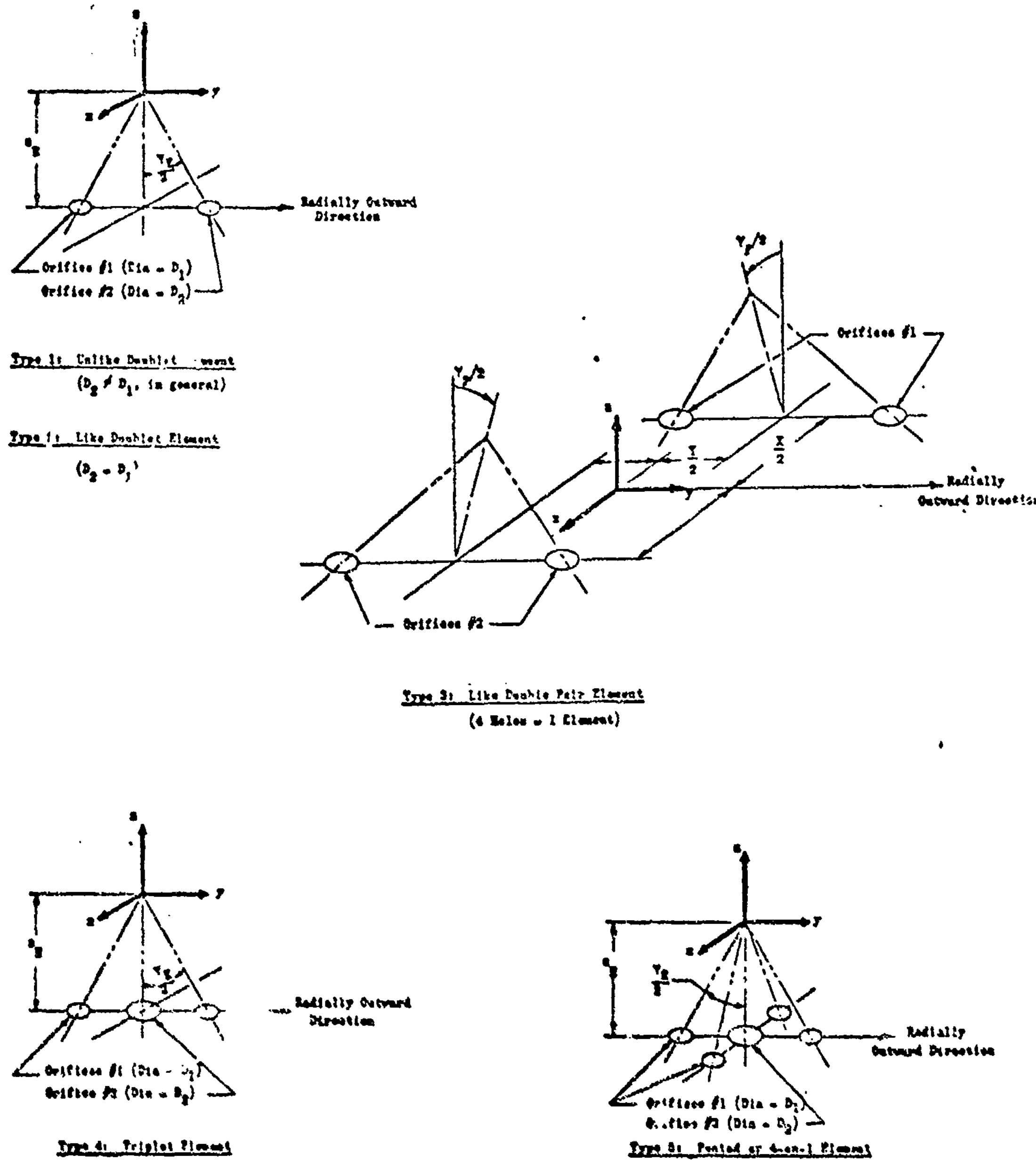


Figure 10. Injection Element Designations and Coordinate Systems

pinging streams while the y axis lies in the plane of the impinging streams. For the 4-on-1 and like doublet pair elements, the geometries specified in Fig. 10 were made as consistent with the doublet and triplet as was conveniently possible. The definitions of x and y axes for the type 8 element are equivalent to those specified for the doublet.

The angular orientation of the (x,y,z) coordinate system of the individual element to the chamber coordinate system is defined in terms of three rotation angles whose respective FØRTRAN names are ALFA, BETA, and GAMMA. If:

1. The element is oriented on the injector such that its y axis (as defined by Fig. 10) is coincident with the chamber radius through the element impingement point, with positive y pointing radially outward, and

2. The z axis of the individual element (as defined in Fig. 10) is parallel to the thrust chamber axis

then the angles ALFA, BETA, and GAMMA have zero values. If the element is not oriented in this "basic" or reference alignment, then

1. ALFA is the counterclockwise angle of rotation around the z axis from its original alignment with the chamber radius.

2. BETA represents counterclockwise rotation around the y axis (in its new position after the first rotation); finally,

3. GAMMA represents counterclockwise rotation around the x axis (in its transformed position after the first two rotations).

For each rotation, "counterclockwise" implies the rotation direction that would be seen by an observer looking along the positive axis toward the origin of the element. Each element is considered to consist of two equivalent orifices designated as 1 and 2. The physical orifices which correspond to these number designations are shown in Fig. F10.

The LISP program also labels the injected propellant as either 1 or 2. The fuel must be chosen as propellant 1 and the oxidizer as propellant 2 because of the combustion gas properties vs mixture ratio tables and because they are expected to bear these designations when data are transferred from LISP to PMSTC.

"Collection" Plane Selection. There are no firm criteria for determining the appropriate axial location for the "collection" plane. The distance downstream of the mean propellant impingement point for the collection plane is generally selected within a range of less than 1/2 inch to 2 or 3 inches. The distance should be related somewhat proportionately to the physical size of the injector element and should in general be sufficiently long enough to allow the spray to spread out across the chamber and/or to overlap with neighboring elements. Also, the "collection" plane should be near the region of initial combustion.

To assist in evaluating the effect of "collection" plane location, up to three locations may be analyzed in a single computer run with the use of inputs ZØM, ZØM2, and ZØM3. When a value of zero is encountered, the additional LISP cases are not run. The final case is the one transferred to the PMSTC subprogram analysis.

PMSTC Input Data

Input data for the PMSTC subprogram block are read by subroutine CINPUT. Stream tube data is initialized from LISP-generated mesh point flow data via scratch data set 2 if ILISP≠0; otherwise, it is read via punched cards.

Size Control Integers. Stream tubes formed from LISP-generated data are grouped into NØZØN annular zones plus a wall boundary zone if NØZØN is less than NRWALL. The greater the number of zones, the more nearly will the correspondence of the radius of an ensemble of spray in LISP be with the mean radius of the stream tube to which it is assigned in PMSTC. The number of zones does not generally have a significant effect on performance. Each NØZØN zone is divided into NSTPZ stream tubes by grouping spray mass from each LISP mesh point according to mixture ratio. NSTPZ should be kept sufficiently large to prevent too much mixture ratio averaging, which directly affects the mixing efficiency. From the standpoint of computing economy, the total number of stream tubes should be kept to a minimum. The program is limited to a maximum of 19 stream tubes.

The number of spray group sizes, NGT, per stream tube is limited to 12, including both fuel and oxidizer groups. If ILISP$\neq$0, subroutine SCRMBL sets NGT=12 and NGF=6, regardless of what input values are read.

The number of axial stations for calculations, starting at ZSTART and ending at the throat plane, is specified with the input variable NP. For readability of the output, a whole number of increments per inch is desirable. and NP can be calculated simply as:

$$NP = \frac{ZT-ZSTART}{\Delta Z} + 1$$

where ΔZ=1/(increment per inch) with a typical range of $0.02 \leq \Delta Z \leq 0.10$.

<u>Combustion Chamber Geometry</u>. The geometry of the combustor is described through the doubly subscripted array APRØF(J,L). This array is entered in coordinate pairs (L=1,2) for each value of J. The values APRØF(J,1) denote axial distances from the injector and the values APRØF(J,2) denote the corresponding chamber diameters at these positions. It is required that distance increase with increasing J and that the array progress from the injector plane to the nozzle throat. That is, APRØF(1,1) is assumed to be zero and APRØF(NAP,1) is the injector to throat distance. The intermediate values with 1>J>NAP are used to describe the wall profile of an axisymmetric chamber. Cross-sectional areas of z-planes lying between APRØF(J,1) and APRØF (J+1,1) are based on linear interpolations on diameter. Therefore, each section of the chamber, except the last, is a section of a cone or a cylinder.

The last section of the chamber is described with a wall profile radius of curvature, RR, through the throat region in addition to the end coordinates, APRØF(NAP-1,L) and APRØF(NAP,L). The resulting surface, which is constructed in AVAR, is a conical surface tangent with the throat wall radius of curvature surface.

Multiple stream tube PMSTC analysis is continued past the throat for up to 25 z-increments. With the throat plane denoted by Z(NP), mirror-image symmetry is assumed such that areas at Z(NP+1) and Z(NP-1) are equal, etc.

Contraction Ratio Tolerance. A throat contraction ratio tolerance, CRTØL, is used as a criteria for satisfying throat boundary conditions in both the single and multiple stream tube analyses. This control becomes redundant when used with the engine balance subroutine, ENGBAL, in which pressure and flowrates are solved as a function of the throat area and are compatible with the throat area when the predicted performance parameters match the corrected ones. For some reason, unknown at this time, the contraction ratio obtained with the ENGBAL solution differs from unity by 1 or 2 percent. Therefore, an adequate tolerance must be allowed on CRTØL (0.05 recommended) to prevent program termination due to nonconvergence.

In the single stream tube analysis, the flow area at the throat, computed from gas continuity with the gas velocity set equal to the local sonic velocity, is divided by the geometric throat area to obtain the throat contraction ratio. For an acceptable solution, the absolute deviation of this contraction ratio from unity must be less than CRTØL; otherwise, parameters are adjusted, and a new pass through the axial increments is performed.

For the multiple stream tube analysis, the throat flow area is calculated differently, but the tolerance is still CRTØL. The throat, or choked flow, area here is taken as the minimum cross-section in the throat region. Also, if the contraction ratio deviates less than three times CRTØL, the next pass through the axial increments is shortened by starting at the beginning of convergence.

PULSE Input Data

The pulse characterization model, PULSE, performs a transient simulation of several sequences of "standard" width pulses and constructs performance tables from which pulse performance of individual pulses can be synthesized. The input data must specify values for the independent parameters of these tables, operating conditions, design data for transient performance and empirical constants.

Size Control Integers and Control Indicators

The number of pulses in each sequence of "standard" pulse widths is specified with NSPACE. The parameter which is varied between these pulses is the pulse spacing, or electrical "off-time' from one pulse to the next. A maximum of 12 pulses in a sequence is allowed for covering a pulse spacing range from the minimum spacing required up to a spacing above which performance is not significantly affected. Once the propellant in the feed system has boiled off, performance as a function of pulse spacing has stabilized.

The number of pulse sequences is specified with NTWALL. Chamber wall temperature is the parameter varied, but only its effect on heat soak-back to the propellant in the feed system for boil-off is accounted for. Energy loss variations with chamber wall temperature is not accounted for here, but is in the duty cycle analysis. A maximum of six pulse sequences, or chamber wall temperatures, is allowed, and the temperatures must cover the range from ambient to steady-state wall temperatures.

The modified Seamans' ignition model, IGN, may be bypassed by entering a "0" indicator for IIGN. Experience with this model indicates that numerical difficulties will cause it to fail and terminate prior to attaining ignition for most cases. Therefore, a "0" for IIGN is recommended.

An indicator for the boil-off model, IBØIL, is provided. Without the boil-off model, most of the performance variation due to pulsing is neglected. Whereas this indicator was useful during computer program checkout, an entry of "1" for IBØIL is recommended in order to include the boil-off analysis.

Heat Transfer Parameters. The heat transfer considerations for pulse-mode operation of an attitude control engine is extremely complex and significantly affects pulse total impulse and mean specific impulse performance. The PMPM program does not attempt to model the complex heat transfer conditions; but, instead, utilizes gross heat transfer coefficients and parameters which must be (1) analyzed with a separate heat transfer analysis computer program, (2) be determined experimentally and/or (3) be used as correlation parameters. There are several steady-state heat transfer parameters: a bulk chamber wall temperature (TCWSS), fuel and oxidizer feed system hardware temperatures (TFSBF & TFSBØ) and heat soak-back rates (QSBFSS for fuel and QSBØSS for oxidizer) for heat transfer from the feed system hardware to the propellants Chamber wall temperature transients are handled in the duty cycle analysis rather than in the transient combustion analysis. Initially, the duty cycle chamber wall temperature is at ambient temperature, and the wall is assumed to heat up, while the chamber is fired, exponentially approaching steady-state wall temperature. Similarly, the wall is assumed to cool while the chamber is not being fired, exponentially approaching ambient temperature. The heating and cooling rates are controlled by the program user through the exponential coefficients CØEHTH and CØEHTC.

Ignition Delay Constant. An ignition delay constant, TAUIGN, may be input in lieu of running the modified Seamans' ignition model, IGN. A combustible gas mixture ratio must exist at the start and during the ignition delay period in order to attain ignition. Substantiated values of ignition delay may be difficult to obtain. Typical values are believed to be on the order of a fraction of a millisecond.

Propellant Valve Parameters. Propellant flow is assumed to be controlled by electrically activated, solenoid type valves. Valve opening and closing response periods are distinctly split between coil energize, or de-energize, time and valve travel time, with the former time consuming by far the major portion of the period. Typically, for a valve opening response time of 5 milliseconds, the valve travel time is approximately only 1 millisecond. Valve coil energize and de-energize response times are calculated as linear functions of applied voltage, with the coefficients being part of the input data. Valve opening and closing movement is specified as part of the input data in the form of tables with fraction of restricted flow area, compared with full open area, as a function of time from the completion of coil energize or de-energize time. Considering the short durations, linear (two-point) opening and closing travel functions are generally adequate.

Propellant Feed System Elements. The propellant feed system flow passages are defined in elements: a line, manifold and injection orifices for both the fuel and oxidizer branches. Cross-sectional area, length and volume must be known to model steady-state and transient fluid flow and the propellant boil-off between pulses. For the line and orifice elements, diameter and length must be specified as input data, with the volume implied assuming a constant cross-sectional area. For the manifold, however, the cross-sectional area may not be constant, nor the flow path length one-dimensional. Therefore, volume and cross-sectional area at the injector are the required input data for the manifold element with an "effective" length implied. This length, relative to the area, is normally short enough to be an insignificant modeling parameter.

DCYCLE Input Data

A mission, or duty cycle, for a pulse-mode engine must be fully specified with input data describing sequentially pulse widths (electrical on-times) and spacings (electrical off-times).

Pulse Sequences. Frequently, a pulse-mode engine is fired in bursts of constant width, equally spaced pulses. A "burst" of pulses of this type is referred to here as a "sequence" of pulses. To minimize input data, duty cycles are specified in terms of sequences, where the number of pulses in a sequence may be as few as one. The input variable, NSEQ, specifies the number of pulse sequences in the duty cycle. Each sequence is described with the number of pulses (NPS), pulse width (PWIDTH), pulse off-time within the sequence (ØFFB), and pulse off-time between the last pulse and the first pulse of the next sequence (ØFFC). For the last sequence, ØFFC should be set equal to the maximum off-time in the PSPACE array in subprogram block PULSE.

PROGRAM OPERATING INSTRUCTIONS

Program operating instructions are presented in this section to specify specific conditions, other than input data instructions, required in processing a computer run with the PMPM computer program.

DECK SETUP

Because of the very large size of the PMPM computer program, the program is often executed in an overlay mode or in separate parts. This may be done for several reasons: (1) to stay within the computer core size limitation, (2) to reduce core size usage with overlay when the computer is run in a MVT (multiple variable task) environment, or (3) to reduce deck size with a partial program for ease of handling.

Overlay Structure

PMPM overlay structure is shown in Fig.11 . The horizontal lines show the level of the overlay with each branch set up to occupy core separately in time from the other branches attached to the same horizontal line. Each subprogram or label common block name (which are enclosed in slashes) occurs only in one segment. Segments are numbered in circles on the overlay chart. The root segment, segment 1, contains, in general, the main control program and utility programs which are used extensively in many branches of the overlay structure. The primary branches, which connect at the overlay A level, are the LISP model in segments 2 through 5, the PMSTC model in segments 6 through 11, and the PULSE and DCYCLE models in segments 14 through 20.

The recommended method for specifying the overlay structure when executing the program (with TDK excluded) is to include in the deck setup the small deck of overlay and insert cards (which are provided) at the end of the link edit section. Insert cards are not provided for the TDK program block, which contains approximately 100 subroutines and many label common blocks. Instead, the order of the delivered deck is arranged to correspond with the

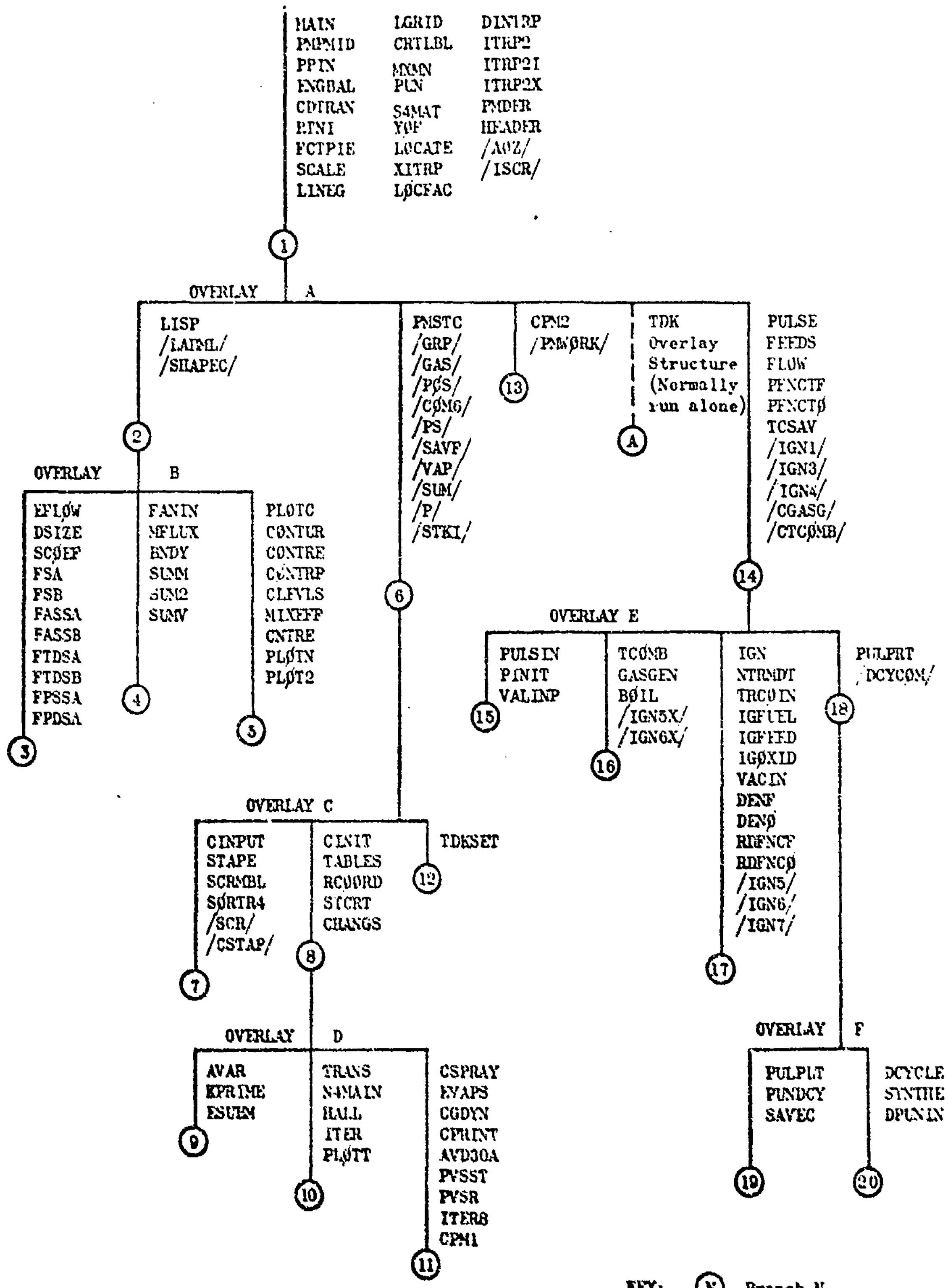


Figure 11 . PMPM Program Overlay Structure

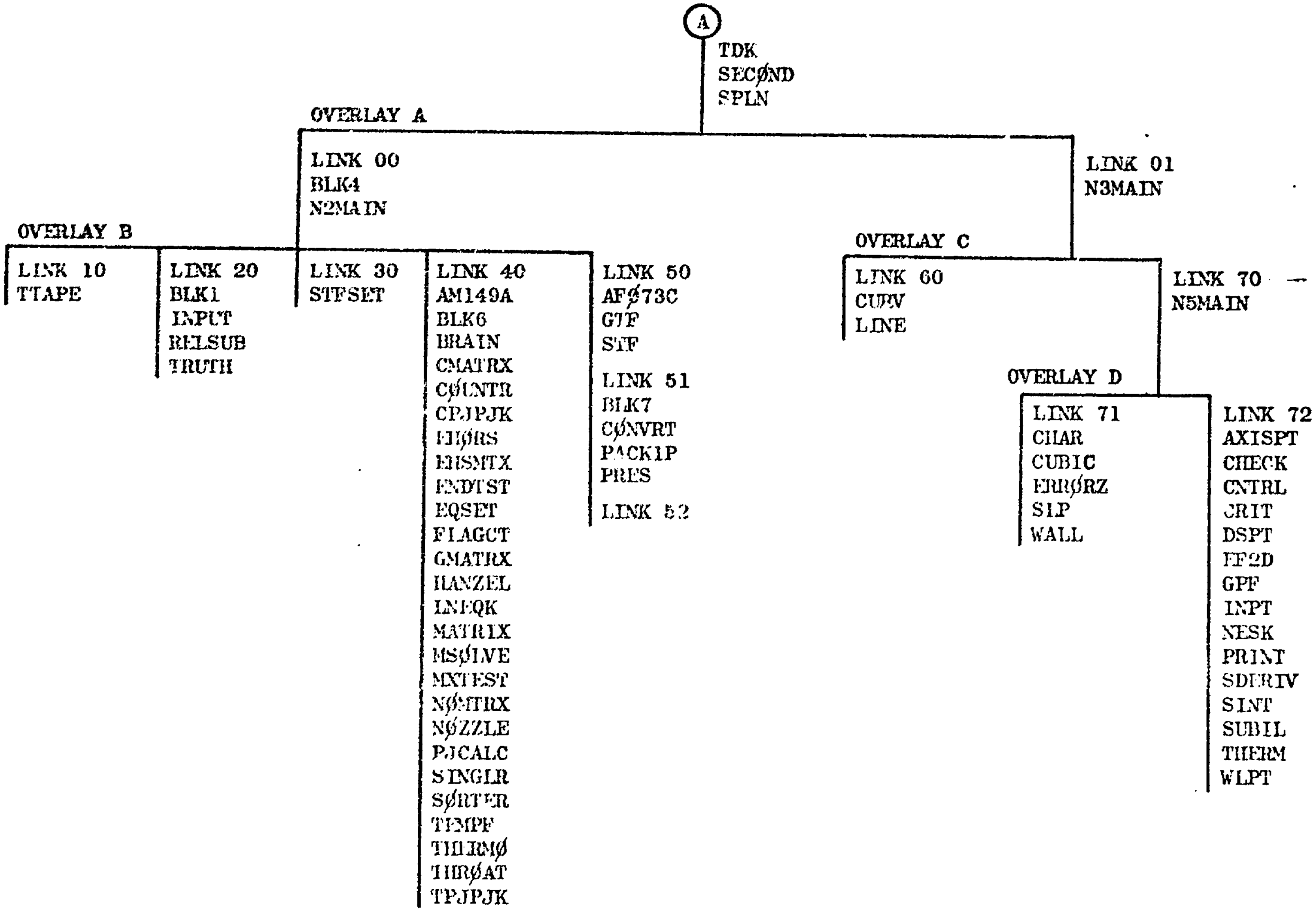


Figure 11. PMPM Program Overlay Structure (Continued)

TDK overlay structure. The overlay cards for running TDK separately from PMPM are to be inserted in the object deck at the head of each overlay branch; i.e., with 2 overlay A cards, 5 overlay B cards, and 2 each overlay C and D cards.

The overlay structure was setup to minimize the computer core size requirements without incurring excessive overlaying during execution. Except for the TDK program block, the segments of the program are generally loaded sequentially with a minimum of subsequent reloading. Overlay is not used in iterative or incremental step-type solutions. However, overlay efficiency on computers having more than the minimum required core capacity can be improved by consolidating the segments to just fill the available core size.

Partial Program Configurations

The generally recommended "complete" PMPM computer program configuration excludes (with the use of dummy subprograms) the very large TDK subprogram block in PMSTC and the IGN model in PULSE, since the nozzle performance analysis with TDK is normally either executed separately or omitted and since the ignition analysis with IGN is inoperable for the general case.

The computer core size required for this "complete" configuration without overlay is approximately 115K words, where the unit K is 1024. The required core sizes quoted here can only be approximate, since size is variable in respect to compiler efficiency, computer system software and buffer sizes, and the word structure. Sizes quoted here are taken from operational data run on an IBM System 360, model 65 computer system with the units of bytes converted to words by dividing by four. The same configuration with overlay requires approximately 53K words of core.

A natural division of the PMPM computer program is between the steady-state model, PMDER, and the pulse characterization, PULSE, and duty cycle, DCYCLE, models. As a rule, the steady-state results should be reviewed before proceeding into the pulse analysis, in which case the program deck might just as well be divided to minimize the deck size, and the number of overlay segments and/or required core size. With dummy PULSE and DCYCLE subprogram blocks, the core requirement without overlay is approximately 90K words. With a dummy PMDER subprogram block, the core requirement without overlay is approximately 66K words.

The CRT plotting routines comprise a sizable section of the source program. These routines are: LINEG, LGRID, and CRTLBL in segment 1 of the overlay structure, all of them in segment 5, STCRT in segment 8, PLØTT in segment 10, and PULPLT in segment 19. Also, there is an extensive number of library routines referenced by these supplied routines. If CRT plotting is not supported by the user's computer facility, the CRT routines should be removed from the program deck and replaced with the following subroutines, either dummy or rewritten to be compatible with the user's plotting equipment: PLØTC, PLØTN, PLØT2, STCRT, PLØTT, and PULPLT. Also, the plotting routines referenced on the overlay insert cards must be deleted or supplemented as the modifications require.

DATA SET USAGE

For normal I/O (input/output) operations in the PMPM computer program, the standard data set reference numbers 5 and 6 are used with the transmittal statements READ and WRITE, respectively. These data sets may refer to separate magnetic tape drive units or a field on a disk pack. The transmittal statement PUNCH, for which the computer system designates the data set number, is used for the punched card output. (At Rocketdyne, data set 14 is used for punched card output, whereas data set 7 is more generally used for this function.) If the CRT plotting routines are used, another data set (number 16 at Rocketdyne) is required, which is also system designated.

Additional data sets are required to transfer data between subprograms and to store and accumulate large quantities of data for delayed processing. These special data sets, which must be defined when running PMPM, are referenced as numbers 2, 3, and 4 when running without TDK. With TDK, 10 and 11 are also required. Table 3 describes special data set usage, the subprograms where the data sets are referenced and variable names used in referencing data sets.

TABLE 3 . SPECIAL DATA SET USAGE

Data Set		
No.	Var. Name	Usage
2	M	(1) Transfer data from LISP to STAPE in PMSTC.
	KSTC	(2) Save data in PMSTC for plotting in STCRT. (3) Transfer data from TDKSET in PMSTC to TDK subroutines BRAIN, LINE, and CHAR.
3	-	(1) Subroutine ITER8 saves and retrieves data for iterating in PMSTC.
	KPSS	(2) Transfer data for PSS array in TDK from subroutine BRAIN to LINE.
4	JTAPE	(1) In PMSTC, CPM1 saves droplet mass flow-rates and residence times and, in PMDER, CPM2 uses this data for calculating the spray depletion functions. (2) Subroutine TTAPE in TDK stores master thermodynamic data from block data and retrieves it in subroutine STFSET.
10	KREAX	Transfer reaction rate tables in TDK from subroutine INPUT to PACK1P.
11	KSTF	Transfer specific thermodynamic data from JANAF unit in TDK from STFSET to THERMØ, PACK1P and THERM.

PROGRAM EXECUTION LIMITS

Limits are generally specified on several computer operating functions to terminate computer execution for nonstandard or excessive operation. In particular, if the program execution gets in an endless loop for some reason, the limits will terminate execution instead of letting the computer get hung-up. Limits which are normally specified include execution time, printed output line count, and number of CRT frames. Normally limits are specified with considerable margin to prevent termination caused by a miscalculation.

Limits vary so greatly with specific cases run that only rough estimates can generally be made from sample cases. For the sample case shown in Volume III of the program documentation, the number of lines of printed output is approximately 18,000 and the number of CRT frames was 30. The CRT output can be determined precisely from the input data, but a margin for miscalculation is recommended here, also.

The limit on execution time at Rocketdyne is based on CPU time, not clock time, since the computer is run in an MVT environment. Computer usage for cost allocation at Rocketdyne is measured in "billing units" (BU's). These BU's are calculated with a formula which includes CPU and channel times, core region size and amount of peripheral equipment used. A BU is roughly equivalent to a minute of clock time for a standard engineering job run by itself on an IBM system 360, model 65 computer. The documented sample case used 11.5 BU's, and the CPU time was approximately 8 minutes. A typical TDK case requires 40 or more BU's, and an IGN case requires on the order of 2 or 3 BU's.

PROGRAM OUTPUT

The PMPM computer output consists of printout, punched cards and CRT graphical plots. Appendix D, Volume III, contains printout from an example case which was run using the input data listed in Appendix C, Volume II. Card images of the punched output appears in the printout. Most of the printout is self-explanatory, but the parameters which are labeled only with their FORTRAN code name need to be described. Input data are printed out in this manner, using the coded names defined in Table 1. Coded parameter names in the printout which are not part of the input data are described in Table 4. A brief discussion of the output by major subprogram blocks is presented in this section.

TABLE 4.

FORTRAN CODES OF PARAMETERS IN PRINTOUT WHICH ARE NOT IN INPUT DATA TABLE

CODE	DESCRIPTION
A1IL	Slope of TDK initial line at intersection with streamline
A1SL	Slope of streamline at intersection with TDK initial line
CD	Nozzle discharge coefficient
CFSF,CFSØ	Fuel and oxidizer feed system flowrate coefficients in ENGBAL
CØMB	Logical variable for combustion (true or false)
CSTAR	Characteristic velocity, c* (used as heading for c* table and for final value)
ECSTAR	Characteristic velocity efficiency (ηc^*)
ECSMXE	Estimated mixing limited ηc^*
EPS1,2,...,6	Area expansion area ratios (ϵ_1, ϵ_2, ... ϵ_6)
EM	Rupe mixing efficiency factor
ERRMR	Deviation of ENGBAL mixture ratio; predicted minus corrected values
ESPIMP	Pulse mean specific impulse efficiency, η_{I_s}
F	False
FF,FØ	Fuel and oxidizer mass flowrate continuity correction factors going from LISP to PMSTC
IP	Pulse number in sequence
ISEQ	Pulse sequence number in duty cycle
ITER	Iteration count in ENGBAL
KPRIME	Table values of static droplet evaporation coefficients
L1, L2	TDK initial line coordinates (sequenced from nozzle wall) which bracket axial, Z, location
ØFF1,ØFF2	Electrical off-time before and after a pulse
ØXFRP	Reduced oxidizer fraction, $\dot{w}_o/(\dot{w}_o + c_m \dot{w}_f)$, where c_m is the midpoint mixture ratio in the combustion gas tables

TABLE 4 (Continued)

CODE	DESCRIPTION
PIEE	Estimated injector end chamber pressure
PMF,PMØ	Fuel and oxidizer feed system manifold pressures
PNS	Stagnation pressure at chamber nozzle
PØVER	Maximum pulse pressure overshoot in percent of steady-state pressure
PWIDTH	Pulse electrical on-time
R1,R2	Factors used to corrected fuel and oxidizer injection flowrates in LISP to correspond with ENGBAL flowrates
RDSL,RDSL2	Radii of a streamline (dividing two stream tubes) at ends of Z increment bracketing the TDK initial line
RHØF,RHØØ	Fuel and oxidizer densities
RVAPFE, RVAPØE	Estimated fuel and oxidizer vaporization efficiencies
SIMEAN	Cumulative mean specific impulse of pulses in a duty cycle
SPIMP	Pulse mean specific imputse
SUMSPF, SUMSPØ	Instantaneous total fuel and total oxidizer mass weights of spray in combustion chamber
SUMTI	Cumulative total impulse of pulses in a duty cycle
SUMW1,SUMW2	Total fuel and total oxidizer spray mass flowrates in LISP
SUMWF,SUMWØ	Cumulative fuel flow and oxidizer flow during a duty cycle
T	True
TCSTR	Theoretical c*
TDRØP	Pulse response time for chamber pressure to drop to 10 percent of steady-state from the off-signal
TGAS	Instantaneous chamber gas temperature
TI	Pulse total impulse
TIA,TIB	Pulse start total impulse and decay total impulse interpolated from tables characterizing a standard width pulse

TABLE 4 (Continued)

CODE	DESCRIPTION
TIDRØP	Total impulse during a pulse pressure drop response period, TDRØP
TIF1,TIF2	Total fuel and total oxidizer injected into chamber in LISP
TIFACT	Pulse total impulse adjustment factor to account for variation in combustion gas energy losses during a duty cycle
TIRISE	Total impulse during a pulse pressure rise period, TRISE
TMFLF,TMFLØ	Total fuel and total oxidizer steady-state flowrates
TØXFRP	Table of reduced oxidizer fraction (see ØXFRP) corresponding with array of mixture ratio, TMR, in input tables of combustion gas properties
TRISE	Pulse response time for chamber pressure to rise to 90 percent of steady-state from the on-signal
TRISE2	Pulse response time for chamber pressure to rise from 10 to 90 percent of steady-state
TSTART	Time into a duty cycle of the on-signal for a pulse
TWALL1,2,3	Chamber wall temperature during a duty cycle at the start of a pulse, at the cut-off of a pulse and at the end of the pulse tail-off period
TWALLM	Chamber wall temperature at the time half way through the on-time period.
VENSF,VENSØ	Velocities of fuel and oxidizer spray ensembles formed during an incremental time period in PULSE
VFSF,VFSØ	Total volumes in fuel and oxidizer feed systems
VIL	Stream tube gas velocity at the Z location where a dividing streamline intersects the TDK initial line
WENSF,WENSØ	Mass weights of fuel and oxidizer spray ensembles formed during an incremental time period in PULSE
WF,WØ	Total fuel and oxidizer mass weight flows during a pulse in DCYCLE
WGEXH	Mass weight of gas flowing through the chamber nozzle during an incremental time period during pulse transient analysis

TABLE 4 (Continued)

CODE	DESCRIPTION
WGF,WGØ	Fuel and oxidizer gas flowrates from LISP to PMSTC
WGFCUM, WGØCUM	Instantaneous residuals of fuel and oxidizer gases in combustion chamber during pulse transient analysis
X1D	Axial chamber location for beginning of the PMSTC analysis
XMRIL	Stream tube gas mixture ratio at the location where a dividing streamline intersects the TDK initial line
XMRMN	Cumulative mean mixture ratio of propellants used during a pulse duty cycle
Z,ZL2	As used in calculating TDK initial line parameters, Z is the first axial step downstream of the intersection of a streamline with the initial line and ZL2 is the axial coordinate of the initial line at Z

ENGBAL Output

The engine balance routine, ENGBAL, is generally called several times throughout a computer run. On the initial call, the ENGBAL input data, coefficients and initial values are printed out. Injected mixture ratio is iterated on in solving the engine balance, and a line of printout is generated for each iteration step. Each engine balance solution is printed out. The solution is based on estimated values of spray vaporization efficiencies, mixing limited c* efficiency and the ratio of injector end-to-nozzle stagnation pressures. At the end of each PMSTC run estimated and calculated values of these parameters are printed out.

LISP Output

The output of the LISP computer program is provided in both the form of tabular printout and of computer-plotted CRT graphs. Also, data are written on scratch data sets to be read and used by the STC computer program.

LISP tabular output is presented in the example case printout. First, there is a tabulation of all input data which permits both a full documentation of the computer run conditions for later analysis and a convenient method to check input for errors if unusual results are calculated. The input data table is followed by a one page table of specific spray distribution coefficient values used for each element specification. As in the example case, this table of coefficients may be preceded by a warning message that some unlike doublet design or flow parameter falls outside the correlation range in the LISP library of coefficients along with values of pertinent parameters. None of the other coefficient subroutines provides such a message. Next, a table cross references (by injector element, the calculated flow rates and drop sizes before evaporation with the read-in element coordinates.

Following the element reference table, there are two extensive tables referenced to the combustion zone mesh points. The first of these tables lists the coordinates of the mesh points in the chamber slice at the collection plane z_0, together with the weight flux, the total collected mass, the three mean droplet velocity components, and the mean drop diameters of each propellant at the mesh points. The total collected mass at a mesh point is defined as the weight flux times the associated area at the mesh point. The values in the first of these tables are based upon cold flow conditions, i.e., no vaporization is assumed between elements and mesh point. The mesh points are listed in ascending order according to radial and angular coordinate. The last column of this table lists the sum of the collected mass of each propellant at all the mesh-points of constant radial coordinate, i.e., lists the radial distribution of the spray mass flux. The second of these tables again lists the coordinates of the mesh points in the chamber slice in the plane z_0, together with the reduced weight fluxes and droplet diameters of the collected spray after evaporation. A mass-weighted average evaporation of the original spray flux to each mesh point is also listed in this table. At the bottom of this table are listed the Rupe mixing factor, E_m, the mixing limited c* efficiency and the overall percent vaporization of each propellant.

Samples of the LISP graphical output are shown in Fig. 12 through 16. Figure 12 shows the mesh system for the chamber slice analyzed and the element origin locations for all injection elements* considered to contribute flux to that slice. Figure 13 is an example of the fuel and oxidizer mass

* This case has only a single injection element which is at the center.

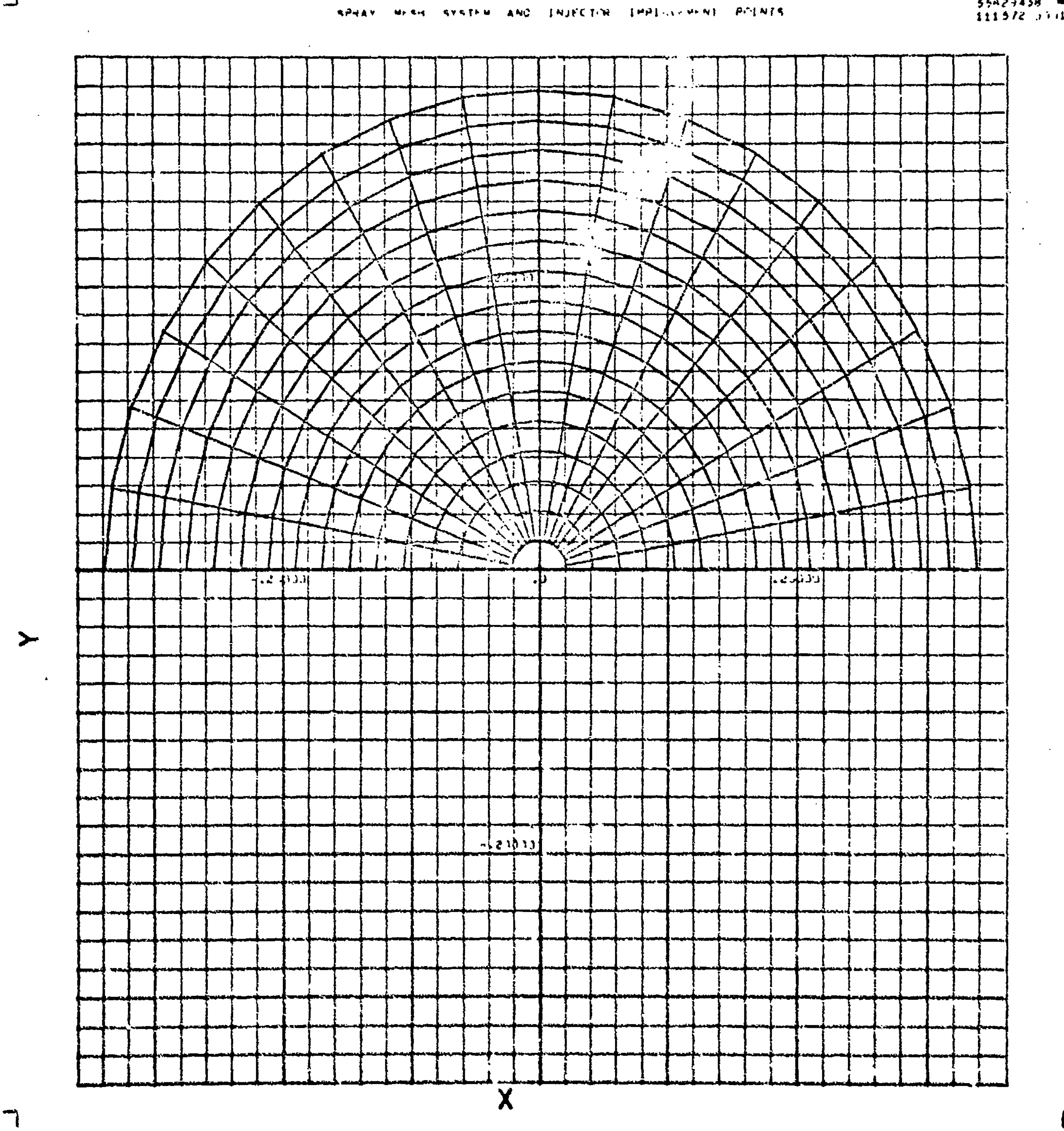


Figure 12. Segment of Injector Analyzed by LISP

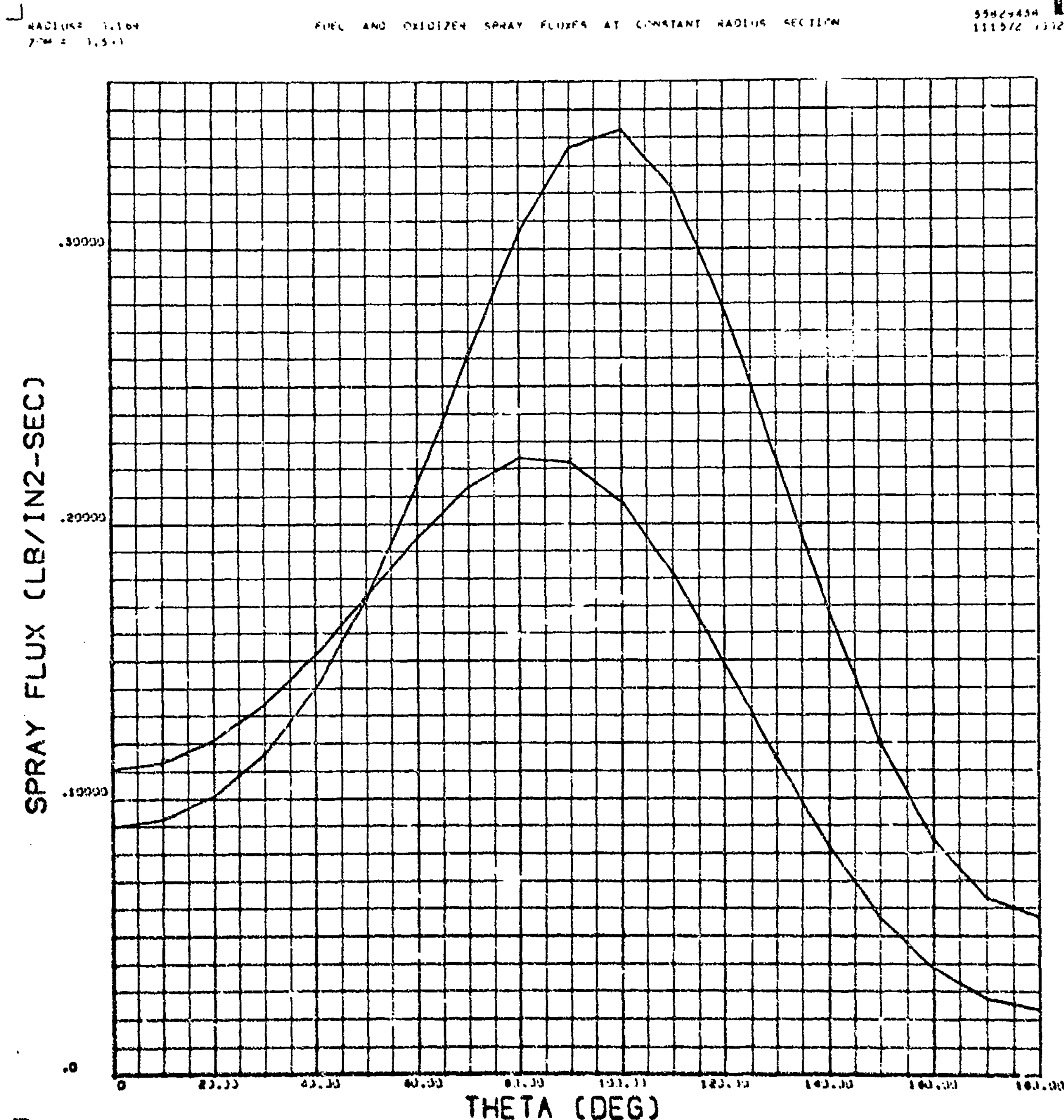


Figure 13. Fuel and Oxidizer Mass Flux Profiles Computed by LISP at a Given Chamber Radius

profiles around the chamber slice at one fixed chamber radius. Figures 14 and 15 are the contour plots of fuel and oxidizer mass flux for the entire chamber cross section. A similar plot for total mass flux is not shown. Figure 16 is a contour plot of a modified fuel fraction function. The expression plotted is given at the top of the figure; it was chosen because it is bounded between zero and unity and has a values of 0.5 at the injection mixture ratio.

PMSTC Output

A sample case of PMSTC computer program printout is included in Volume III. Input data are written out immediately as they are read in. This documents the data used for the particular case as well as showing whether or not the data were read-in properly. The input section should be examined for each case run to be sure that the intended input data were actually used.

Input data transferred from LISP are not printed out, but a table of diagnostic data from subroutines STAPE and SCRMBL is printed. Parameters appearing in that table are:

- SUMW1,2 - Total fuel, oxidizer spray flowrates summed over all mesh points in STAPE
- WGF,Ø - Gaseous fuel, oxidizer flowrates
- TIF1,2 - Total fuel, oxidizer flowrates transferred from LISP
- FF,FØ - The ratio TIF1/(SUMW1 + WGF), etc.
- K - The number of circular rings of mesh points from LISP
- SMBL - Total flowrate assigned to the wall boundary layer stream tube
- PCTT - The ratio SMBL/(TIF1 + TIF2)
- ØTT - The product PCTBL*(TIF1 + TIF2)
- N1,N2 - The indices of circular rings of mesh points in a given geometric zone
- SUM - The cumulative total flowrate in a geometric zone and those set up prior to it

The stream tube initialization data are tabulated and simultaneously punched out in cards.

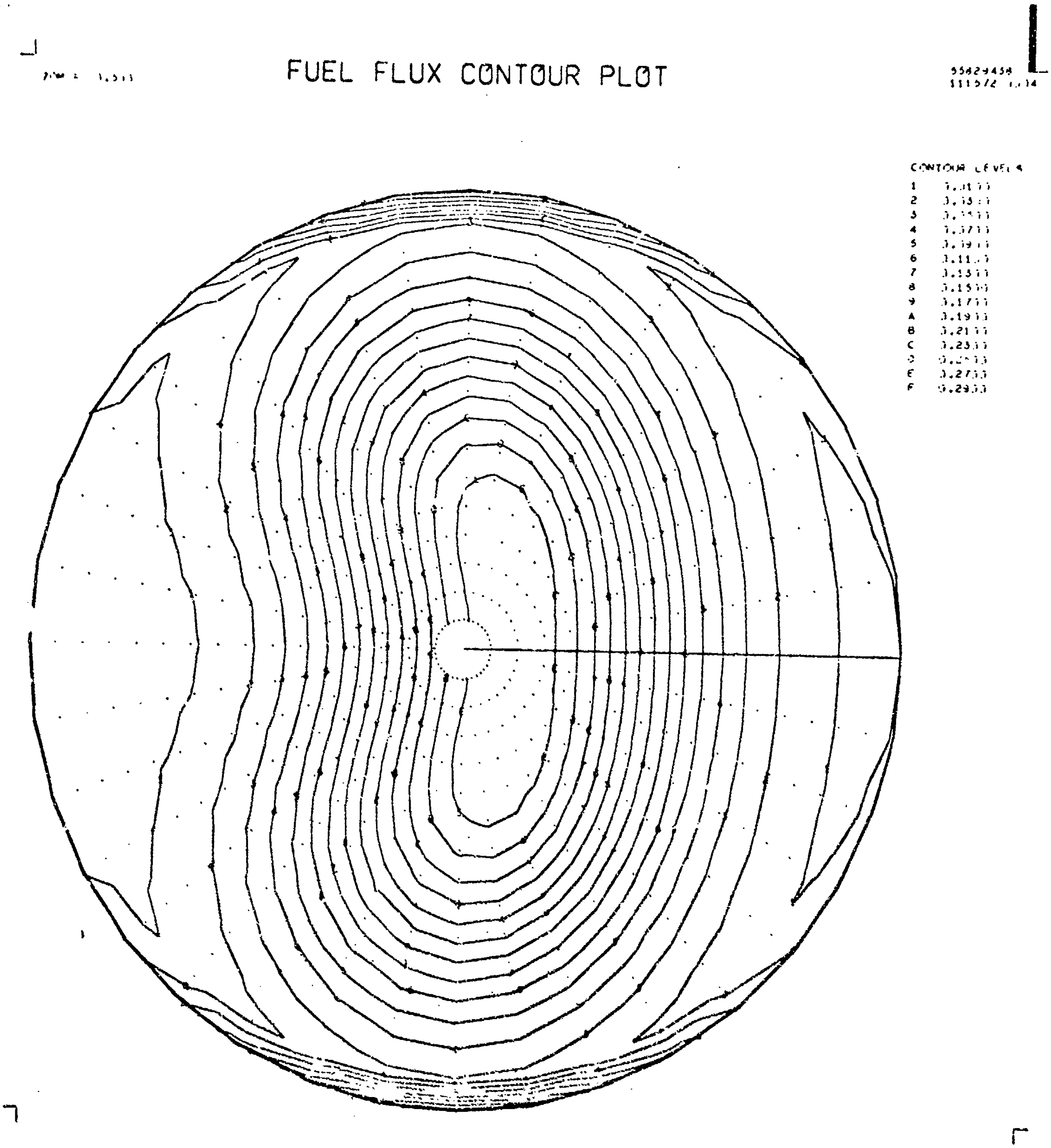


Figure 14. Contour Plot of Fuel Mass Flux Computed by LISP

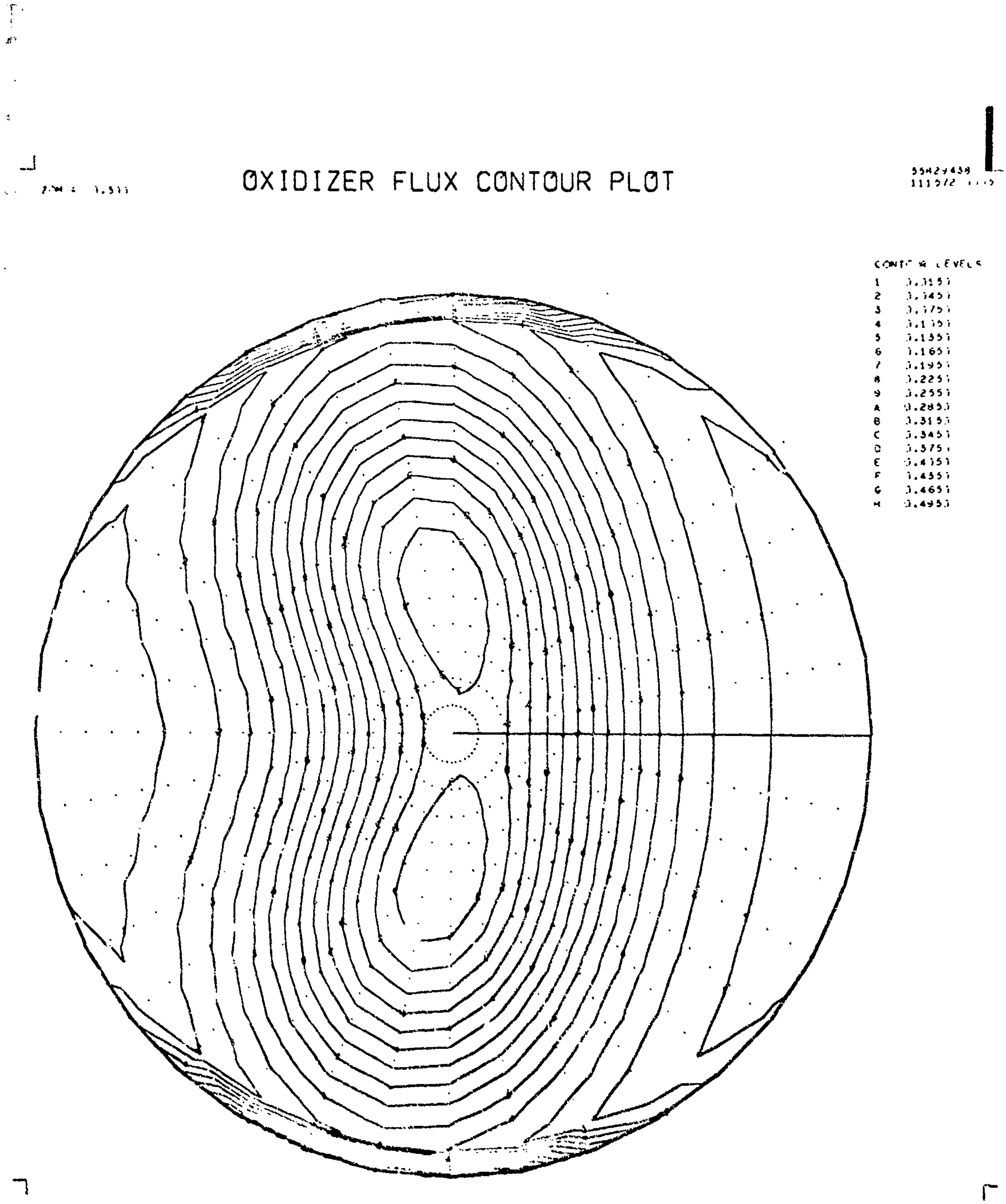


Figure 15. Contour Plot of Oxidizer Mass Flux Computed by LISP

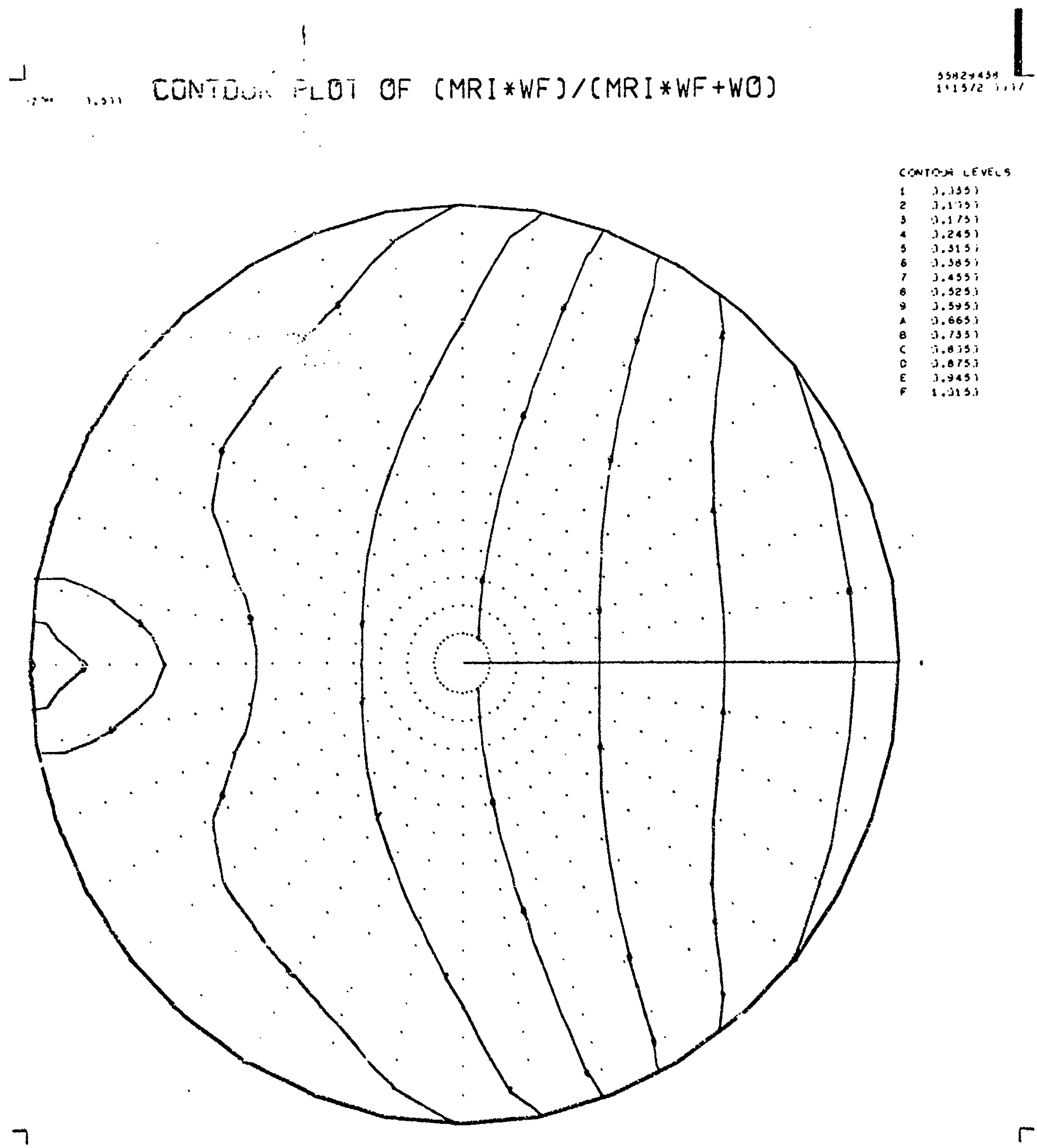


Figure 16. Contour Plot of Modified Fuel Fraction Computed by LISP

Based on the stream tube initialization data, a table is printed out of stream tube total flowrates and overall mixture ratios. This table is followed by values of the Rupe mixing efficiency factor, E_m, and a mixing c* efficiency for the stream tube flows. The latter represents an upper limit for multiple stream tube c* efficiency, since it corresponds to complete evaporation and burning of sprays within all stream tubes. These mixing efficiency factors will differ from those calculated in LISP because of the gas distribution in PMSTC and the combining of stream tubes versus mesh point flows.

Subroutine AVAR sets up the array of chamber areas and writes out a table of chamber geometry information. Similarly, subroutine KPRIME computes and writes out tables of evaporation coefficients.

Single stream tube analysis is preceded by writing out a one-page table of input total flows and averaged spray and gas parameters. During single stream tube analysis, data are written out as they are generated. At each z-plane to be printed, complete gas and propellant spray group data are given. Additionally, the percentages of propellants evaporated and burned are listed and volume number mean propellant droplet diameters, D_{30}, are computed.

Two values each of flow area and contraction ratio may be given. Where the gas flow is subsonic, these should agree with each other precisely, whereupon the second set is not printed. At or near the nozzle throat plane, the two sets may disagree because the gas velocity has been set equal to sound speed and the local nozzle area adjusted to satisfy mass flow continuity. The contraction ratio calculated from continuity at the throat plane is used as a multiplier (if it differs from unity by more than CRTØL) to adjust initial plane chamber pressure for a next iteration of single stream tube analysis. After the throat plane data are written out, an engine balance is calculated and printed.

When the foregoing alnalysis has converged on its solution, a performance summary sheet with c*, thrust and specific impulse is printed. Next, the input value of nozzle radius ratio and calculated value of mean nozzle expansion coefficient, γ, are used by TRANS to generate transonic flow region isobars. The reduced corrdinates and flow directions for each of 20 points along each isobar are written out, beginning with the furthest downstream isobar and progressing upstream. Additionally, for the $\alpha = 0$ isobar, the absolute coordinates are written out for 40 points. TRANS also generates a CRT plot of isobars, which is displayed in Fig. 17.

Multiple stream tube analysis follows the foregoing single stream tube and TRANS analyses. Stream tube input data are re-initialized and some additional data are written out to more completely define the initial-plane conditions. Initial-plane pressure is taken from the engine balance solution which is performed just prior to the multiple stream tube analysis.

At each prescribed z-plane for printing multiple stream tube results, complete definitive data for combustion gases and propellant sprays are written out. Local chamber area and contraction ratio are given; additionally, overall precentages of the propellants evaporated and burned are listed.

At the throat position and intermittently downstream, diagnostic-type printouts containing data concerning dividing streamline intersections with the $\alpha = 0$ isobar are inserted between the regular z-plane printouts. A summary table of these data is given near the end of the multiple stream tube printout. Finally, a long summary table is given of the stream tubes' outer radii at each z-plane. This is terminated with the minimum value of the sum of stream tube areas, the ratio of that value to throat area ratio and the instantaneous weight of the gas in the combustion chamber. Another engine balance is performed using the latest calculated values of vaporization and mixing efficiencies, and ratio of injector end-to-nozzle stagnation pressure. The magnitudes of the deviations in these calculated and the previous predicted values determine whether or not all, or a portion, of STC's multiple stream tube analysis will be repeated. If so, it is readily apparent in the printout. Figure 18 is a computer

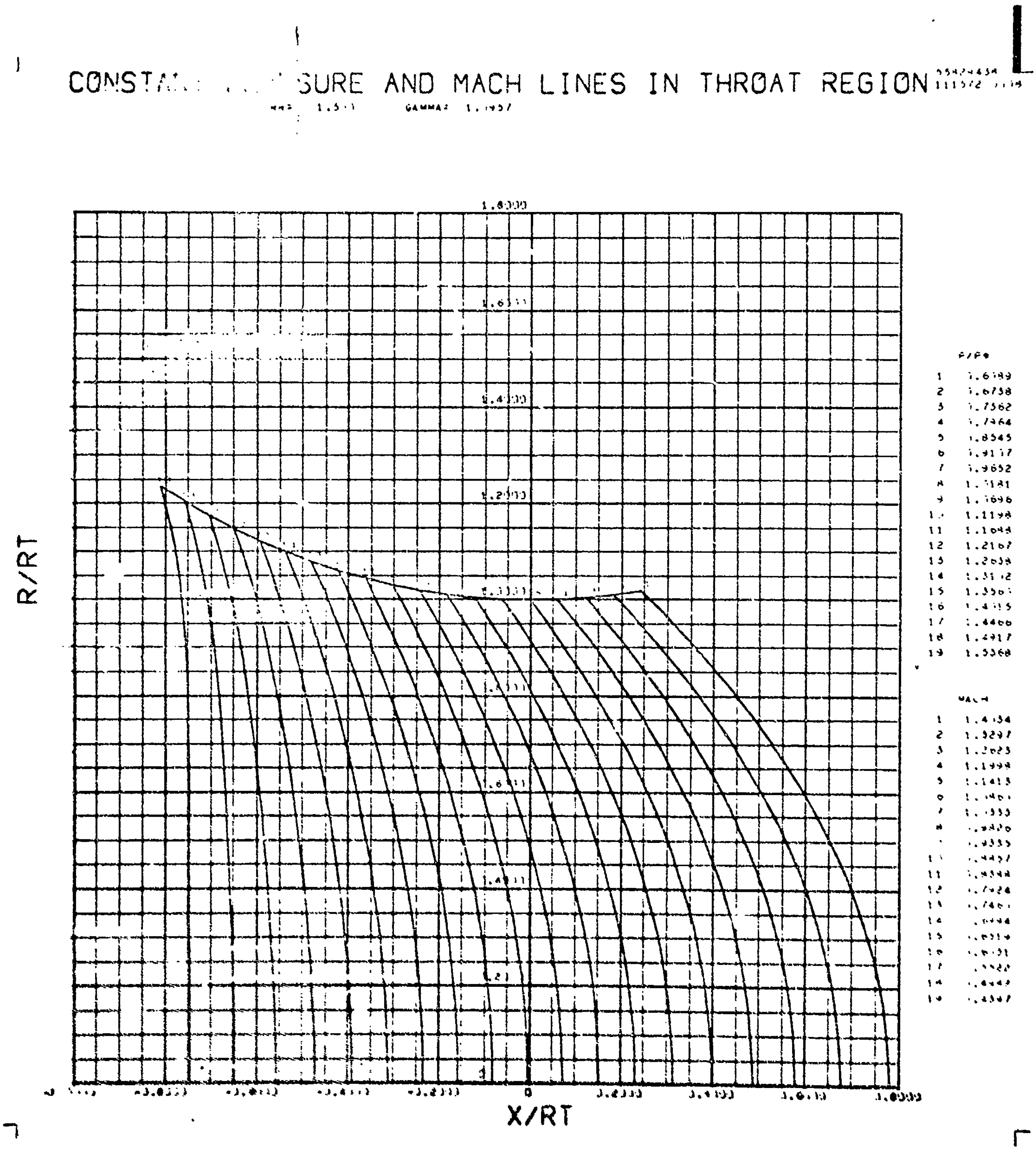


Figure 17. Isobars Showing Nozzle Pressure Distributions
Calculated by Subprogram TRANS

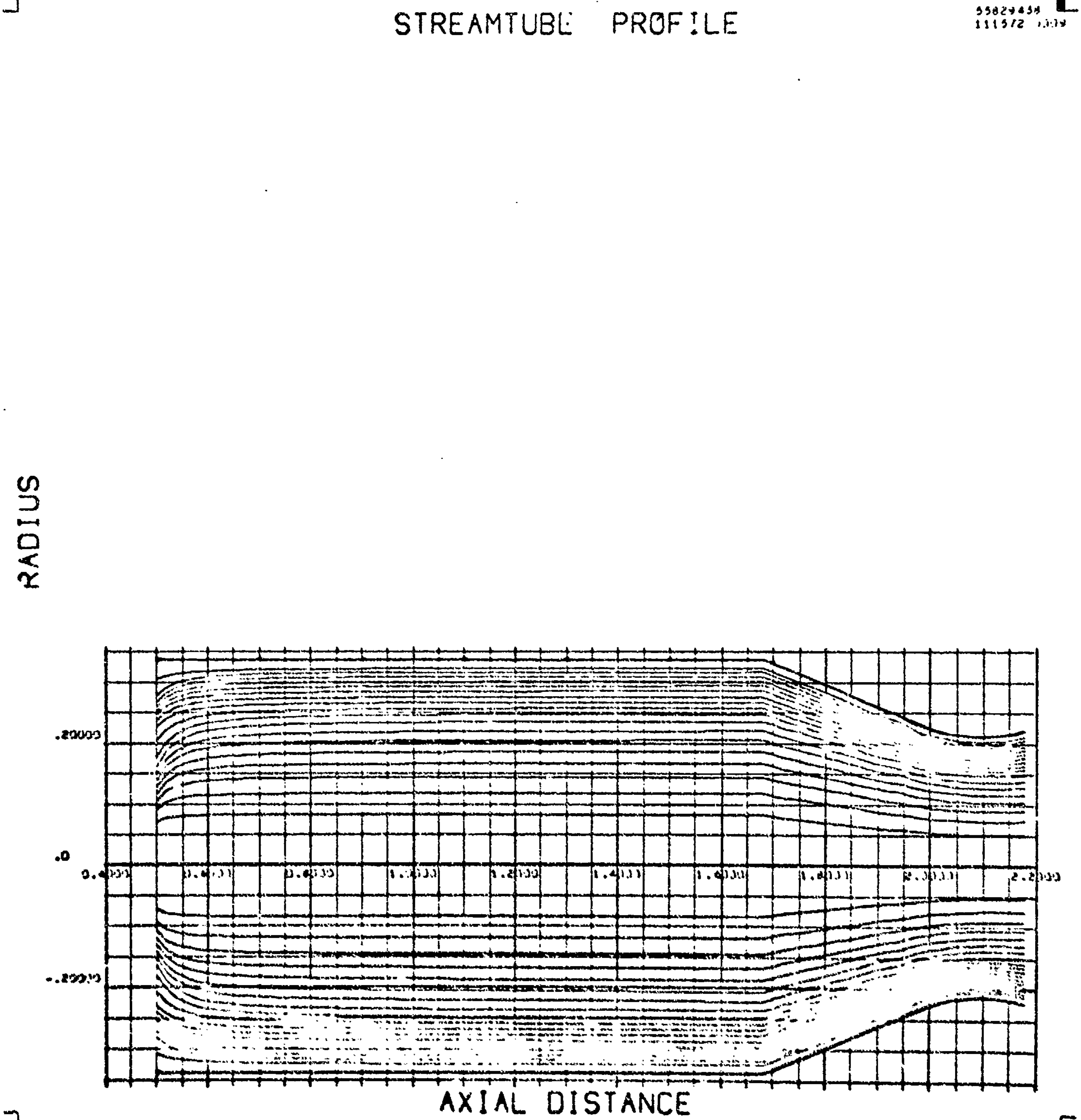


Figure 18. Computer-Plotted Stream Tubes Calculated in PNSTC

plotted graph showing the stream tubes' outer radii along the entire chamber length.

Following the last pass through the multiple stream tube analysis, an updated performance summary sheet is printed and a table is printed which lists the data punched by STC for subsequent use in running the TDK subprogram.

Fuel and oxidizer spray depletion functions, which are the mean time traces of the mass of a spray droplet, are calculated in PMSTC for use in PULSE. This data are tabulated in the printout, punched on cards and plotted by the computer (Fig. 19).

PULSE Output

Following the printout of the PULSE input data, an extensive table of transient pulse performance data is printed out (optional) with a one page summary of pulse performance at the end of each pulse. In the transient table, the following parameters are tabulated: time, thrust, chamber pressure, reduced oxidizer fraction of chamber gas, weights and velocities of fuel and oxidizer ensembles formed during time increment, nozzle flow for time increment, accumulated chamber gases and propellant spray, and gas temperature. Logical parameter CØMB is also tabulated, which indicates whether combustion is present or not. Additional diagnostic type data may be printed out by option. Computer plots are shown of reduced pulse thrust and pressure (Fig. 20) and flowrates and oxidizer fraction (Fig. 21).

Following the printout of the last pulse, a parametric table of pulse performance characteristics is constructed from the transient data. A summary of the table is printed out, and the complete table is punched on cards, whch is also listed in the printout.

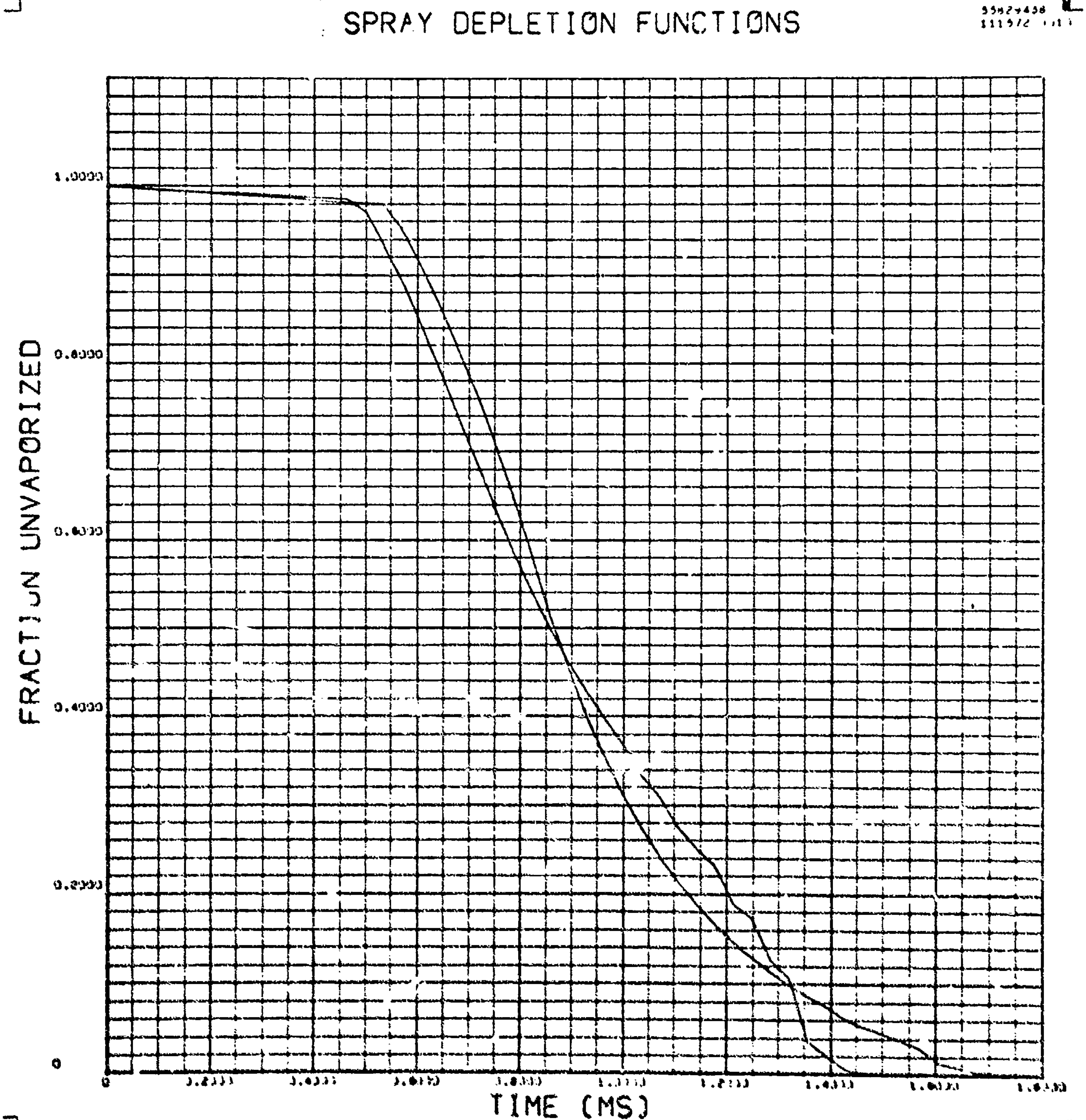


Figure 19. Mean Fuel and Oxidizer Spray Depletion Functions Calculated in PMSTC

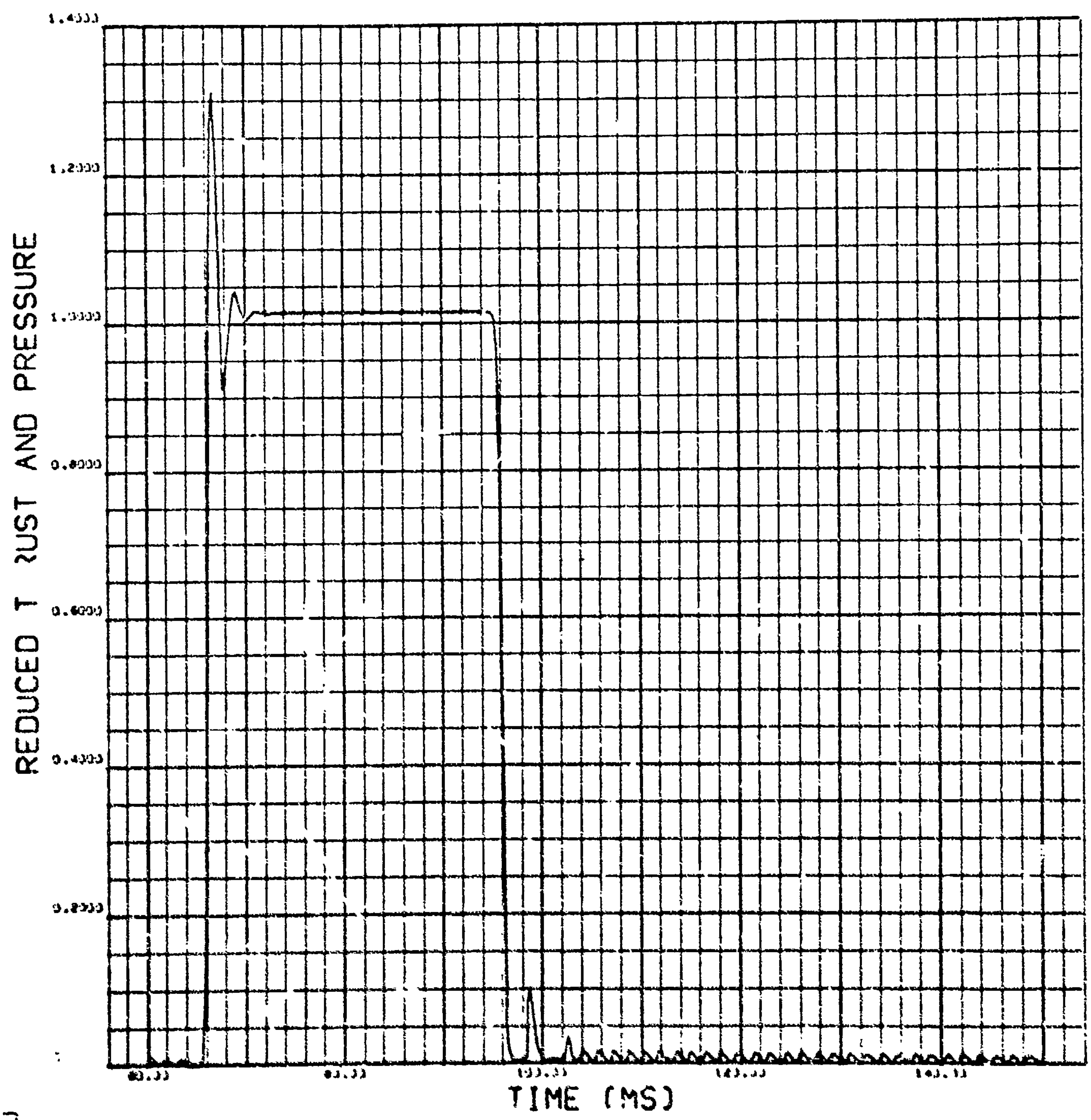
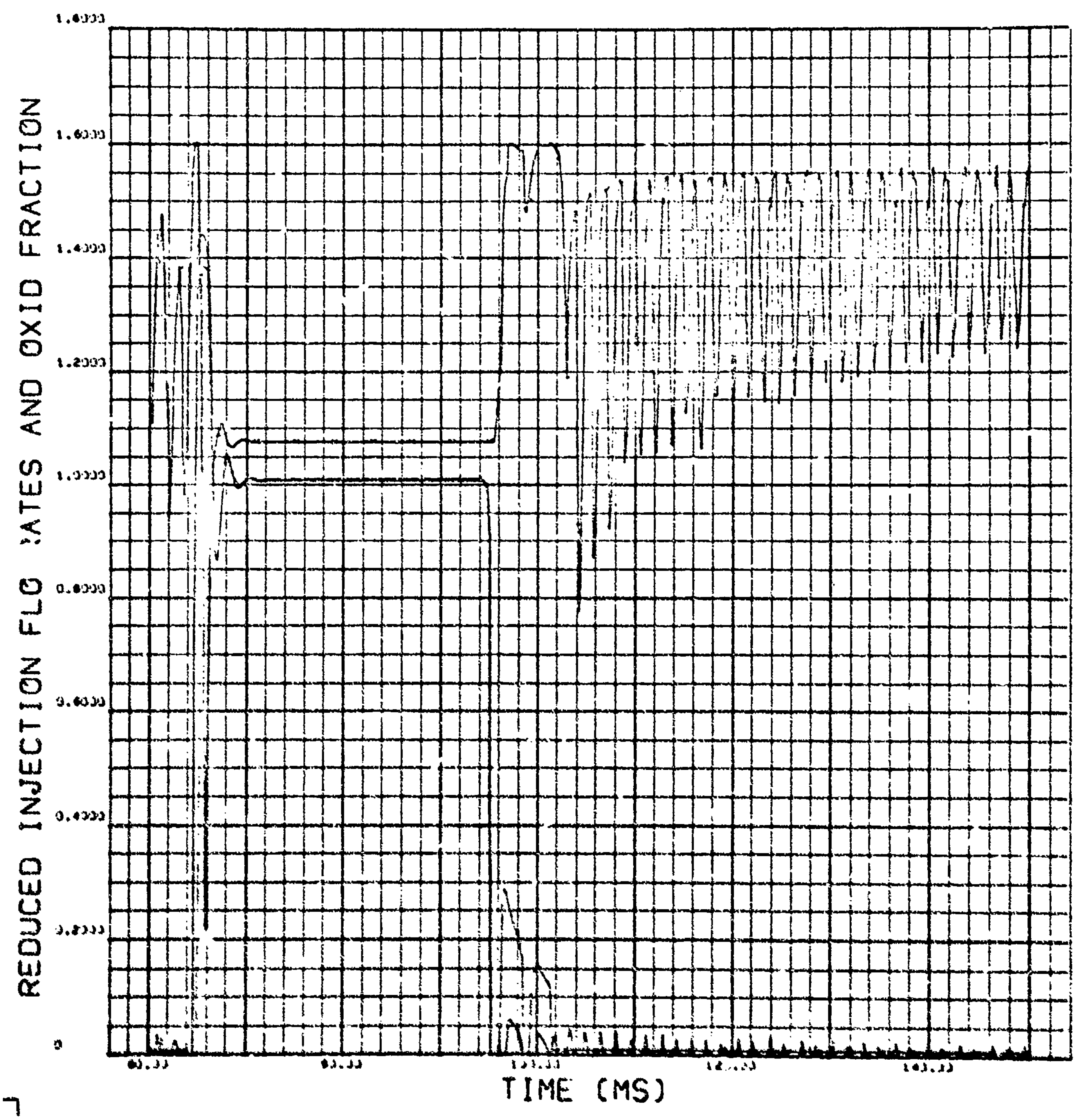


Figure 20. Reduced Pulse Thrust and Pressure Calculated in Subprogram PULSE



Fig're 21. Reduce Flowrates and Oxidizer F.action Calculated in Subprogram PULSE

DCYCLE Output

The duty cycle output from DCYCLE consists of printout only. Two formats for pulse data are available by option: a full page printout (the same as in PULSE) or a three line printout. Generally, most of the pulses will be printed with the short format with only one to three full page printouts per pulse sequence. The first line of the short format printout lists the: time into the duty cycle of the on-signal; electrical pulse on-time; off time before and after the pulse; chamber wall temperature at start; cutoff, end of tail-off and at midpoint of on-time. The second line lists the: total impulse factor to correct for variations in energy losses during a duty cycle; total fuel and oxidizer flow; total impulse; pressure rise response times; pressure drop response time; and the maximum pressure overshoot. The third line lists the: start and decay total impulse bits interpolated from PULSE tables; total impulse bits during pressure rise and drop response periods; and mean pulse specific impulse and specific impulse efficiency. Values are tabulated under column heading using FORTRAN coded names. For more detailed description on these parameters check code descriptions in Table 4.

Cumulative pulse duty cycle performance data is printed out on a single line at the end of each pulse sequence and each full page pulse printout. On this line, cumulative fuel and oxidizer flows, cumulative total impulse, mean specific impulse and mean mixture ratios of consumed propellants are printed.